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A GROUND STATION FOR THE NIMBUS WEATHER SATELLITE AUTOMATIC PICTURE TRANSMISSION SYSTEM

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OCTOBER 1967

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

A GROUND STATION FOR THE NIMBUS WEATHER SATELLITE AUTOMATIC PICTURE TRANSMISSION SYSTEM

(Developed and Operated by the Authors as High School Students Participating in the 1966 National Science Foundation Summer Student Program)

Carl Eslinger

Sumin Tchen

October 1967

GODDARD SPACE FLIGHT CENTER
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ABSTRACT

This report describes a Nimbus Automatic Picture Transmission (APT) system ground station set up by the authors while participating as high school students in the National Science Foundation 1966 summer student program at Goddard Space Flight Center. Their project had two objectives: (1) to give the students the opportunity to work in a technical environment in order to supplement their formal education and (2) to prove the theoretical simplicity of the APT system by having relatively inexperienced persons set up an inexpensive, operational ground station. The authors completed the project successfully by receiving and processing Nimbus APT weather pictures on a regular daily basis. They proved the simplicity of the APT system by mastering the technology in a short period of time and then setting up their ground station, plotting the spacecraft's orbits, tracking the spacecraft with an antenna modified by themselves, and receiving weather pictures equal in quality to those of other APT ground stations.

Foreword

During the summer of 1966, the GSFC Test and Evaluation Division participated in the Summer Research Program for Superior High School Students sponsored by the National Science Foundation. Two of these students, Carl Eslinger and Sumin Tchen, were assigned to set up equipment to receive pictures from the Nimbus Automatic Picture Transmission System. They received help and guidance from a supervisory engineer, Mr. Julius Lewis.

Since the results of this project were intended to serve as a model that could be implemented by students in almost any high school science laboratory, equipment and materials that would be available to such laboratories were used insofar as was possible. The project was very successful. Messrs. Eslinger and Tchen summarize their work in this report in their own words. There has been minimal editing in order to achieve a direct student-to-student communication link.

D C Kennard, Jr
Program Preceptor
Test and Evaluation Division

Since the Nimbus Automatic Picture Transmission (APT) System was designed specifically as a relatively inexpensive and simple system for obtaining satellite weather photographs, the decision was made by the Test and Evaluation Division of Goddard Space Flight Center to test its feasibility as part of the National Science Foundation summer student program. Although the students chosen for the project, Carl Eslinger of Suitland High School and Sumin Tchen of Wilson High School, were excellent students, they had had little formal training in the specialized technology associated with the Nimbus satellite and the APT System. The purpose of the project was to acquaint them with this technology and to supplement their formal education.

The project involved establishing goals, teaching the authors the information required to complete the project's goals, and guiding them through the course of the project, providing help where necessary and criticizing their performance when necessary. The material to be taught the students consisted of the fundamentals of the Nimbus satellite, the APT system, and the APT ground station. These fundamentals included orbital mechanics, spacecraft telemetry, rocketry, and mathematics. Armed with this knowledge, the two students used their own ingenuity and available equipment to receive the APT telemetry from the Nimbus spacecraft and obtain weather photographs. Thus, their goal to set up an inexpensive ground station that could be duplicated by any high school science department as a student project, was achieved.

Philip Yaffee for Julius Lewis
Project Supervisor

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A GROUND STATION FOR THE NIMBUS WEATHER SATELLITE AUTOMATIC PICTURE TRANSMISSION SYSTEM

by

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INTRODUCTION

The Nimbus satellite tests advanced meteorological equipment in an operational environment. It also serves as a stable platform for many of the systems initiated under the Tiros program.

Nimbus has a unique three-axis coordinate system that keeps the command section of the spacecraft always pointed toward the earth (Figure 1). Sun sensors, located on the solar panel shafts, control the movement of the solar panels, and the two horizon scanners sense and correct the pitch and roll of the satellite by controlling flywheels and steering jets (Figure 2).

The Nimbus satellites are launched from the Western Test Range into a nearly circular (80 degrees retrograde) north-to-south polar orbit. This orbit, plus a midnight launch time, places the satellite so that it will pass near any spot on the earth's surface at

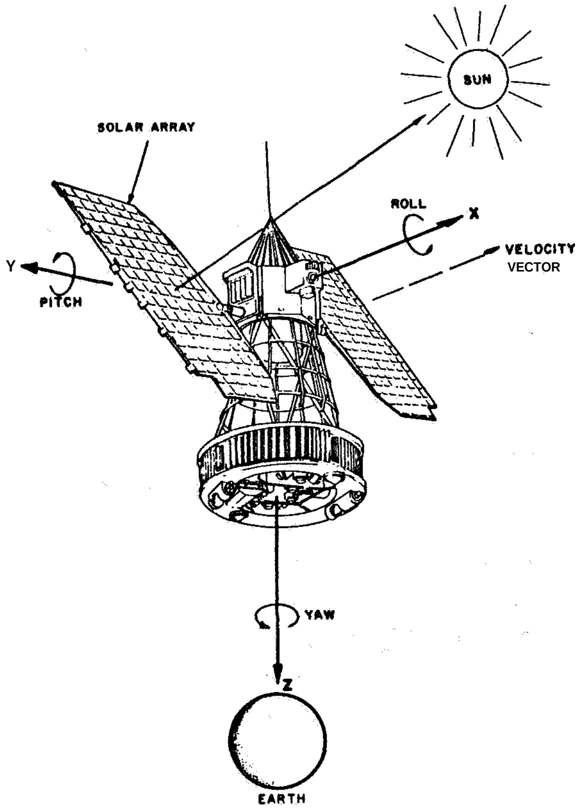

Figure 1. Nimbus Coordinate System

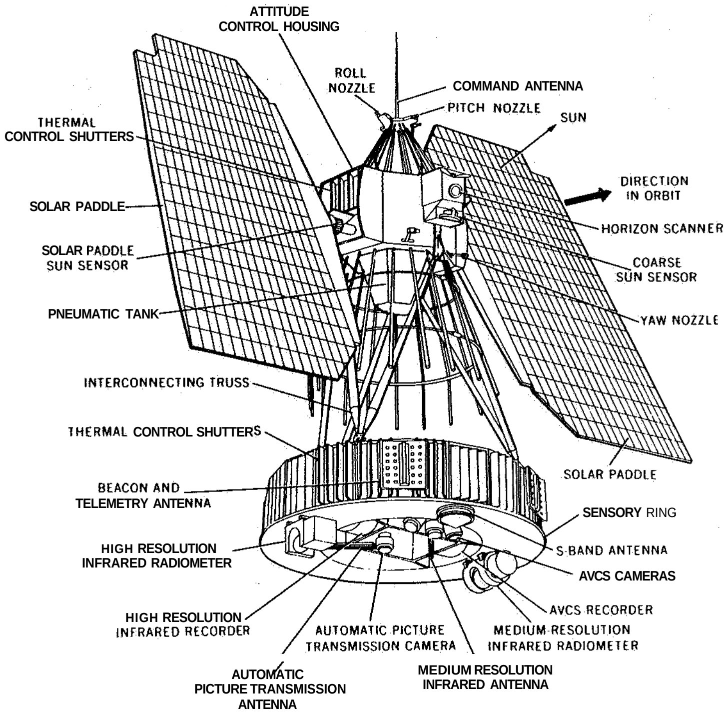

Figure 2. Nimbus Deployed Configuration

a time close to local midday or midnight. Once in orbit, Nimbus stands 12 feet high from the tip of its command antenna to its base, which is 4-3/4 feet in diameter. Its solar panels measure 11-1/6 feet from one side of the satellite to the other. These panels contain 10,944 solar cells that furnish the spacecraft with 450 watts of electric power. There are also seven storage batteries for use during the hours when the spacecraft is in darkness.

In the launch configuration aboard the Thor-Agena booster, the satellite's solar panels and antennas are folded as seen in Figure 3. When the spacecraft achieves orbit, the panels unfold and the spacecraft orients itself toward the earth (Figure 4). Once this has been achieved, the various systems aboard are turned on. The Nimbus C (the second Nimbus launched) has four meteorological experiments on board. These systems are the High and Medium Resolution Infrared Radiometers, the Advanced Vidicon Camera Systems (AVCS), and the APT System.

The High- and Medium-Resolution Radiometers detect minute differences in the infrared radiation emitted by the earth and its cloud cover during the night hours. The pictures that these systems send to earth are in shades of black and white corresponding to the radiation received from areas of heat and cold, respectively. The intensity of the radiation received by the satellite varies as the altitude of objects such as clouds varies. Therefore, these

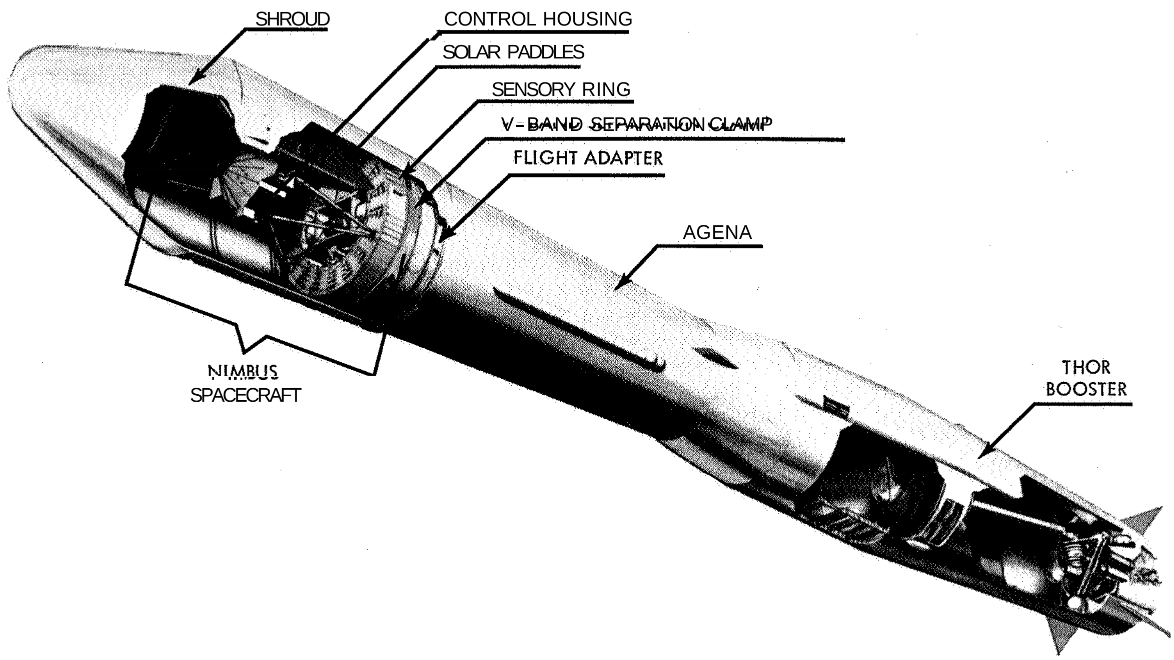

Figure 3. Nimbus Folded Configuration

pictures can be used to calculate the altitudes of land features and clouds.

The Advanced Vidicon Camera System sends an oblong, three-panel picture back to earth from its three cameras. The composite picture formed by these cameras covers an area of about 750,000 square miles and has a resolution of one-half mile. The pictures taken by this system are stored on magnetic tape on board the spacecraft and are normally played back every two orbits to either the Nimbus command station at Rosman, North

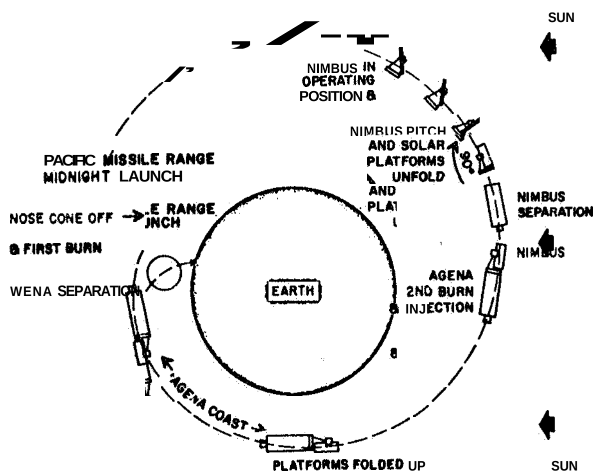

Figure 4. Nimbus Launch Sequence

Carolina, or the one at Gilmore Creek, Alaska. This camera system was designed to assure complete coverage from one orbit to the next. (Figure 5).

The APT System contains a camera with a 108-degree lens. The picture formed by this daylight-operating system covers an area of 1 million square miles and has a resolution of 2 miles. At the earth's equator, there is a gap in the picture coverage of this system between successive orbits.

When the APT camera shutter opens for its 15-millisecond exposure, the image is focused onto a photoconductive material. The image is then transferred to a polystyrene storage layer where it is scanned and transmitted immediately via a 136.95-MHz FM/FM signal at a rate of 4 scan lines per second. The entire sequence for the transmission of the 800-scan line picture takes 208 seconds. The erasure, exposure, development of the picture, and the transmission of a warning signal takes place during an 8-second stage of this sequence. The actual transmission of the picture takes place during the remaining 200 seconds. The APT System uses an amplitude-modulated 2400-Hz FM subcarrier in conjunction with the 136.95-MHz FM carrier wave. The pictures taken by the APT system are broadcast directly to earth by means of the carrier wave. Figures 6 through 10 are typical pictures received and reproduced at the ground station from the APT System.

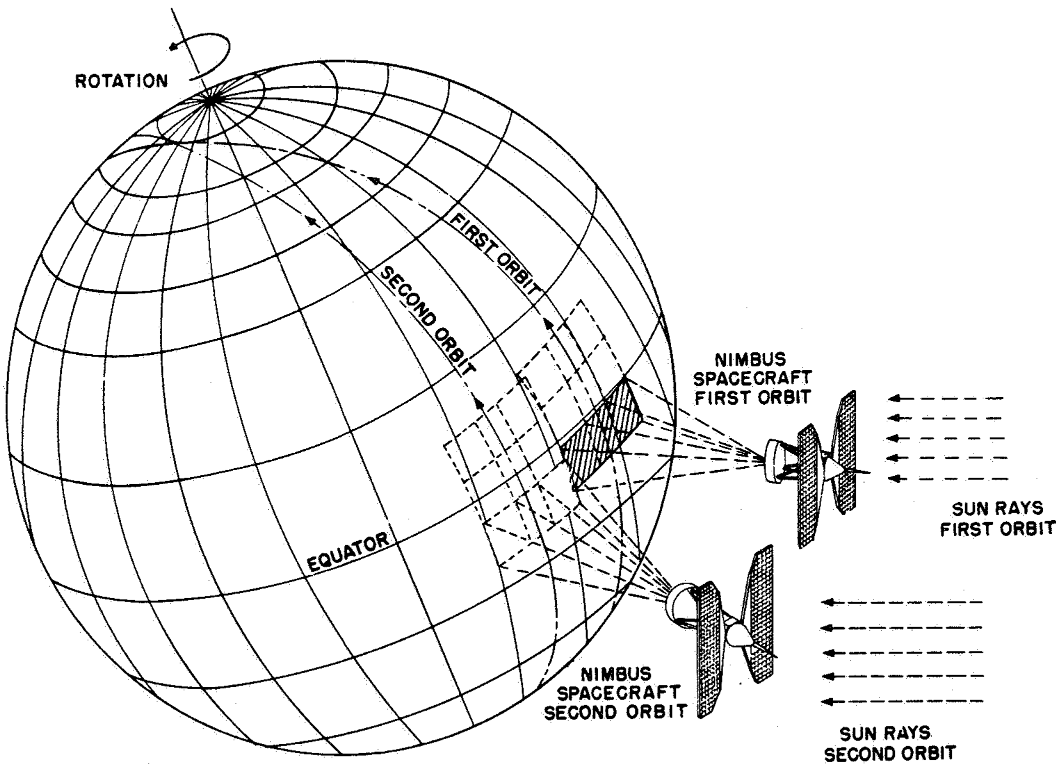

Figure 5. Diagram Showing AVCS Coverage of Two Successive Orbits

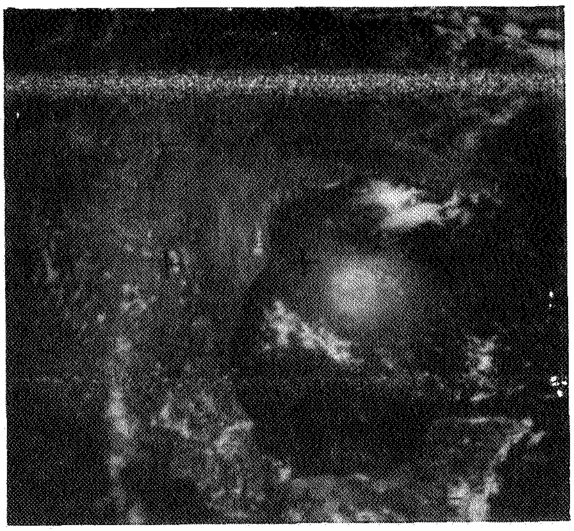

Figure 6. The Yucatan Peninsula As Seen from Nimbus C

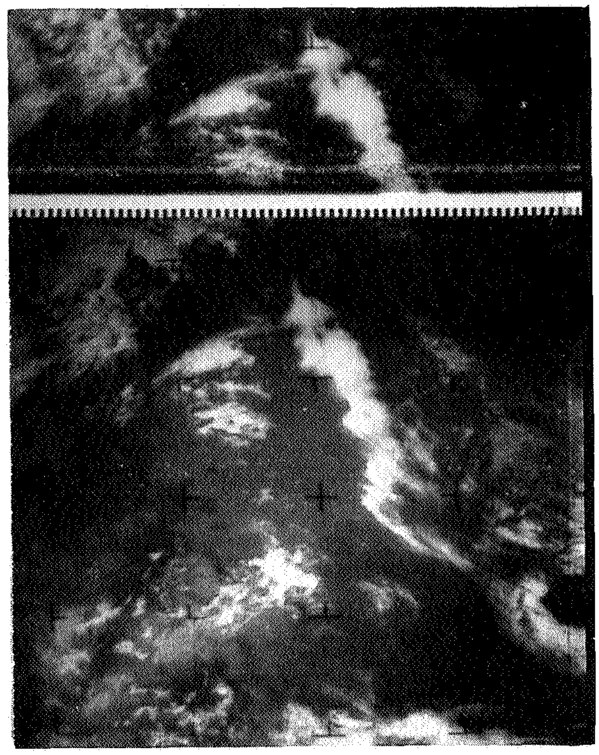

Figure 7. The Midwestern United States, Showing 1-1/2 Pictures Transmitted from the Spacecraft. The Band Across Photo is the Start Tone Command Transmitted by the Spacecraft.

THE GROUND STATION

The Nimbus APT System was designed so that a relatively simple and inexpensive ground station could receive real-time meteorological pictures from the satellite. The ground station described in this report (Figure 11) consisted of an antenna, preamplifier, receiver, tape recorder, variable filter, and a facsimile recorder (Figure 12).

Antenna

The antenna (Figure 13) is a 136-MHz Yagi with approximately a 10-db gain and a beam width of 35 degrees. It was found that both azimuth and elevation control were necessary in order to track the satellite and eliminate most of the noise and other interferences. A simple elevation control, designed to supplement the existing azimuth control, was found to be highly effective (Figures 14 and 15). The horizontally polarized antenna gave best results when it was pointed directly at the satellite.

The two most important elements of the antenna used in this system are high gain in the 10-db range and a tracking capability that will assure a signal-to-noise ratio that is high enough for clear pictures. (The 39th edition of The Radio Amateur's Handbook (1962), pages 453 to 464, contains specifications and construction suggestions for a 136-MHz Yagi antenna.)

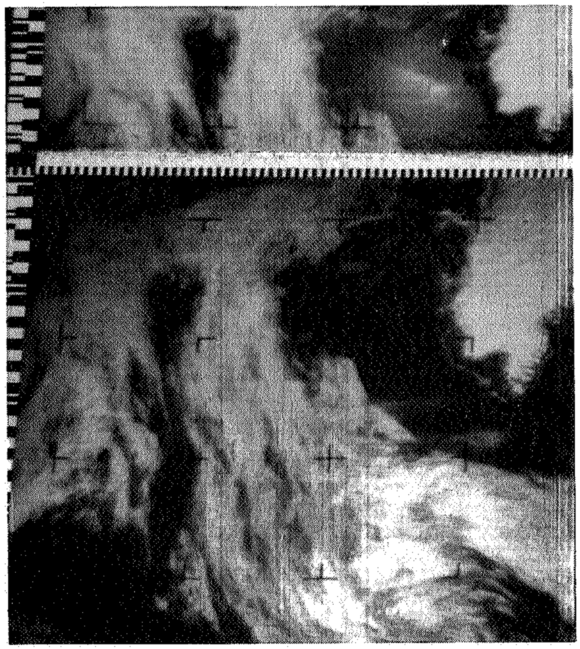

Figure 8. Cloud Cover over the North Atlantic

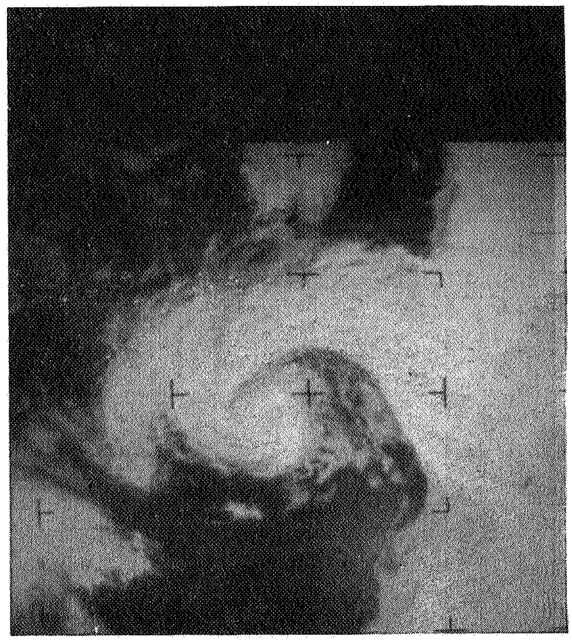

Figure 9. A Storm in the Mid-Atlantic

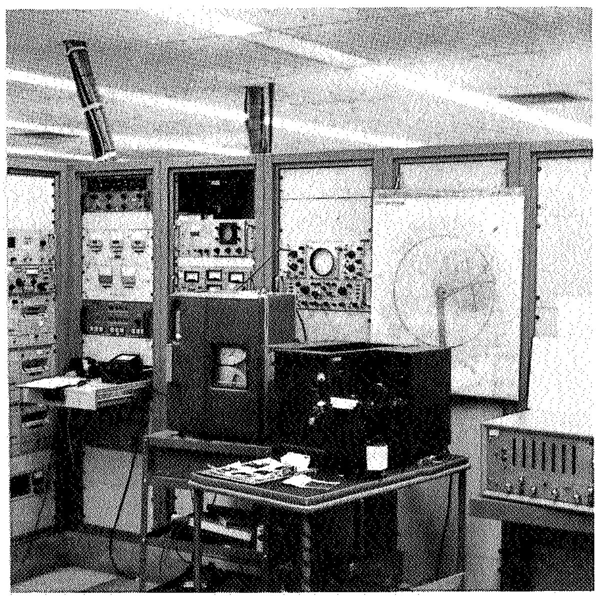

Figure 10. Frontal Pattern Off the Coast of Greenland

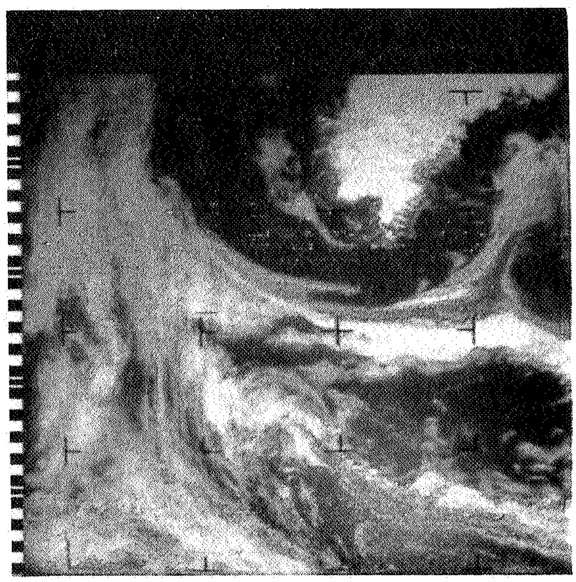

Figure 11. The Completed APT Ground Station

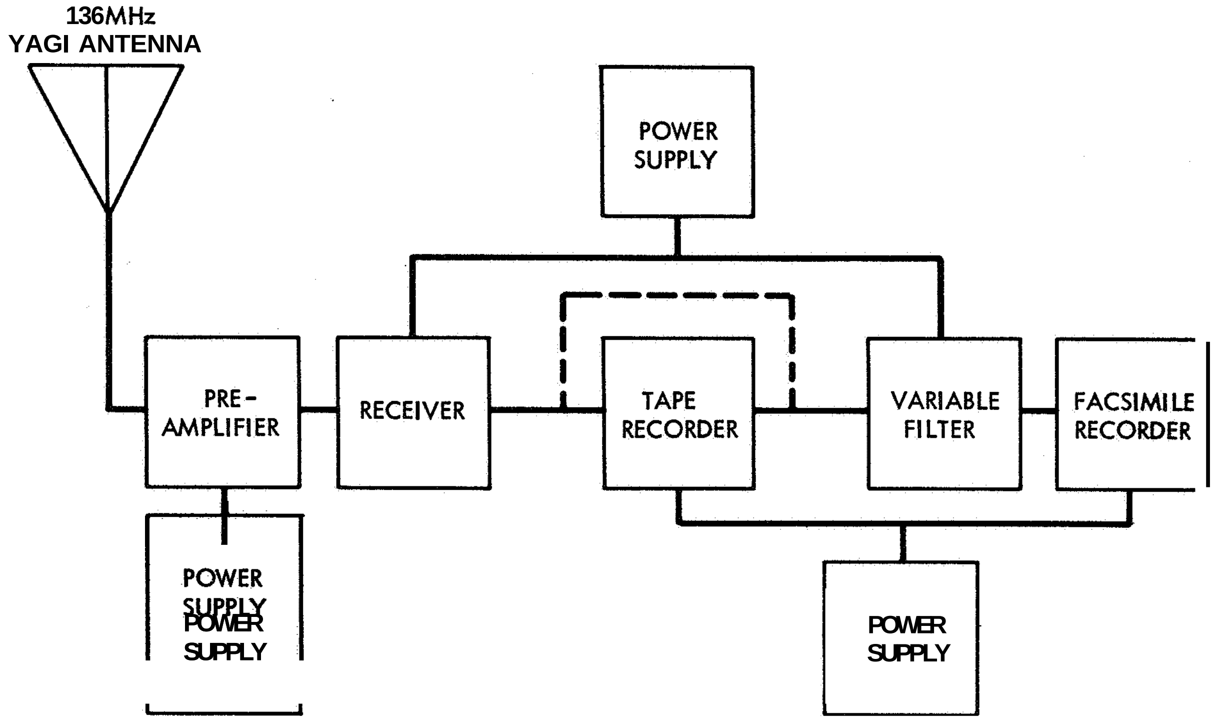

Figure 12. Block Diagram of **APT** Ground Station

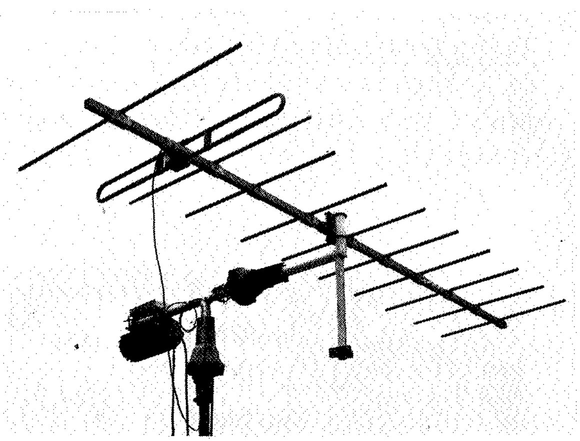

Figure **13.** Yagi 136-MHz Antenna

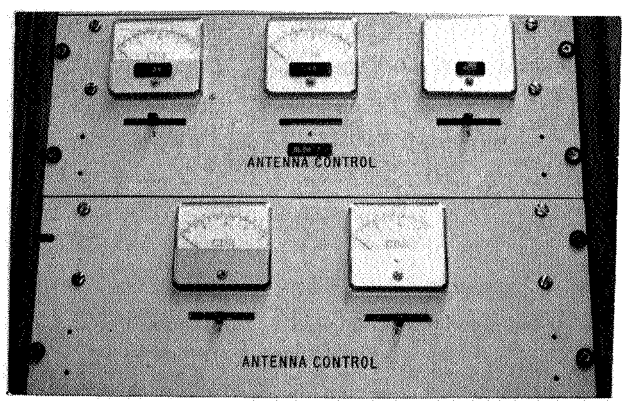

Figure **14.** Antenna Controls

Preamplifier

The purpose of the preamplifier is to maintain an effective signal-to-noise ratio as the signal travels from the antenna on the roof through a coaxial cable to the receiver. To achieve this purpose, the preamplifier is installed at the antenna site. The preamplifier that was used had a gain of 15 db and a noise figure of approximately 3 db. Since the device was to be installed in the open air, a weatherproof, insulated container was used. Station WSM-TV of Nashville, Tennessee, suggests a preamplifier that they designed for their APT station. Relatively easy to construct, the preamplifier has a gain of 12 db and a noise figure of 2.5 db (See Appendix B for details). Any preamplifier that is used in an APT system should have a gain of approximately 10 to 20 db and a noise figure of approximately 2 to 4 db.

Receiver

A Defense Electronics type TMR-5A FM receiver (Figure 16) with an IF bandwidth of 100 KHz and a wide-band demodulator was used. To keep the receiver tuned to 136.95 MHz, a crystal frequency control unit supplemented the variable frequency oscillator. The basic requirements for a 136-MHz FM receiver used in an APT System are a bandwidth of at least 30 KHz and a noise figure of less than 8 db. Some receivers that could be used are a police receiver (monitoradio), a modified 144-MHz or 150-MHz amateur receiver, or a surplus World War II SCR-609.

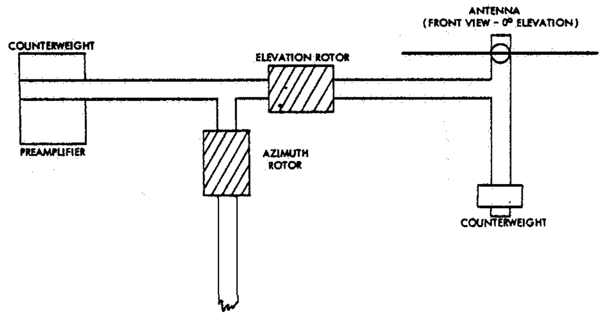

Figure 15. Antenna System Schematic Diagram

Variable Filter

The variable filter was invaluable in removing extraneous noise that otherwise could have ruined the picture. The filter used was an SKL Model 302 (Figure 17) set at a high-pass of 2350 Hz and a low-pass of 2450 Hz. (The Radio Amateur's Handbook, pages 564-567, suggests various high- and low-pass filters that are relatively easy to construct.)

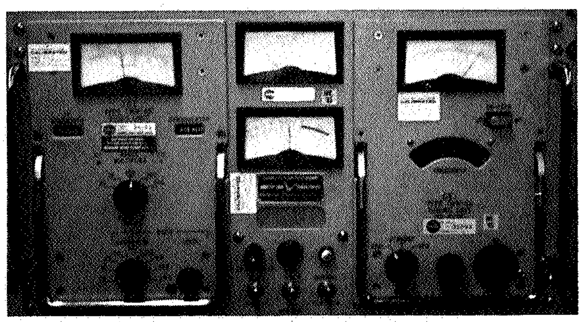

Figure 16. Type TMR-5A Receiver

Facsimile Recorder

The facsimile recorder used was an Army surplus Westrex (Figure 18) using type 42 Polaroid film. This machine was set at its high-scan rate so that it would be compatible with the scan rate of the satellite picture transmission. The recorder automatically synchronizes its line sweep with the sweep of the satellite's equipment and otherwise prepares itself before each picture upon receiving a 300-Hz phasing (warning) tone from the satellite. Occurring during the 8-second PED cycle, this prepares the facsimile recorder to receive the video information and synchronizes the recorder with the satellite vidicon scanning beam,

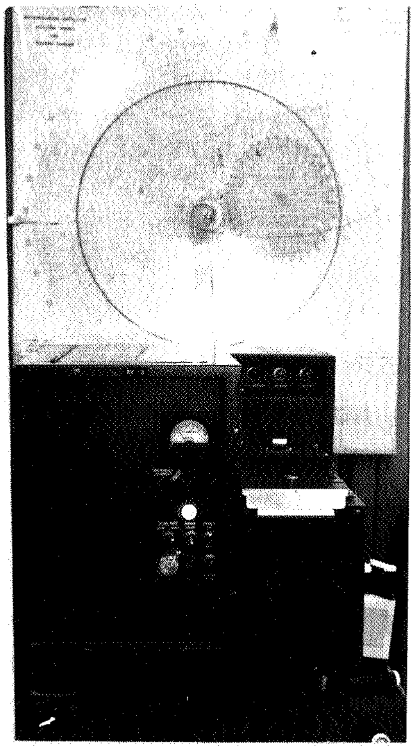

Figure 18. Facsimile Recorder

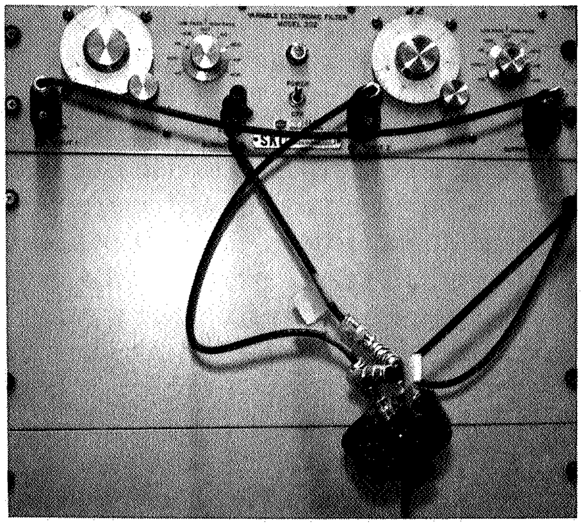

Figure 17. Variable Filter

Changing the contrast of the pictures was made possible by varying the current level to the recording lamp, or by adjusting the machine's black and white bias controls. In this manner, it was possible to obtain the six to seven shades of gray that are essential for picture clarity.

The facsimile recorder contains a tuning fork oscillator and frequency divider combination that synchronizes the recorder with the satellite sweep rate. The 300-Hz start tone is detected by a tube-relay flip-flop in this system. The relay then stops the current flow and thereby starts the synchronization process. Once the recorder becomes synchronized, its major mirror will oscillate at a rate that is compatible with the line-by-line transmission of the satellite pictures (see Appendix B for a block diagram of the facsimile recorder).

When the recorder is synchronized, it is ready for the transmission of a picture by the satellite. The received satellite signal is amplified, rectified, and sent to the recording lamp. From the recording lamp, the light passes through a condenser lens, front surface mirror, and aperture. From the aperture, the light passes to an oscillating mirror and finally onto the film (see Appendix B for a schematic diagram of the optical scanning system).

Station WSM-TV developed a system whereby a 561A Tektronix Oscilloscope could be used in place of a facsimile recorder. The oscilloscope was used primarily because it has a rectangular face and therefore could produce a picture without any of the corner losses that would be encountered with the use of a round face.

The sweep rate of the oscilloscope is synchronized with the satellite, and a Polaroid camera is attached to take a 200-second exposure. The synchronization process is accomplished by first passing the signal through a phase-lock oscillator and comparator (see Appendix B). This device also acts as a narrow-band filter for the 2400-Hz signal from the satellite and as a device for partial prevention of picture distortion caused by tape recorder wow and flutter during playback. The 2400-Hz signal from the phase-lock oscillator and comparator synchronizes the oscilloscope sweep to 4 lines per second by counting down in a ratio of 600 to 1 in the frequency divider (see Appendix B). The oscilloscope sweep lines are continually regulated by the vertical sweep circuit (Appendix B) so that they will be arranged in the proper order and will form a complete picture with no two lines on top of each other.

Tape Recorder

An Ampex 1300 FR tape recorder (Figure 19) was used to record the satellite's signal for later playback. This machine had very little wow and flutter and therefore produced pictures that were only slightly distorted. The tape recorder was found to be invaluable when adjusting facsimile recorder contrast in order to highlight certain features of a picture.

Oscilloscopes

Two oscilloscopes (Figure 20) were used during the course of operations. One was used to monitor the real-time signal from the satellite for the purpose of tuning the receiver, and

Figure 19. Tape Recorder

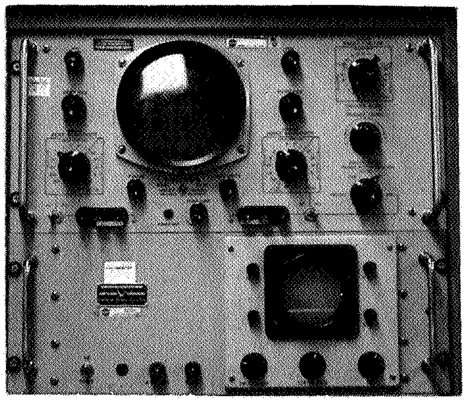

Figure 20. Oscilloscopes

the other was used to monitor the tape recorder output. The oscilloscope used in monitoring the satellite proved invaluable because it gave an accurate indication of the strength of the incoming signal from the satellite.

GROUND STATION OPERATION

The operation of the ground station during a satellite pass was relatively simple. The only real problems arose in tracking the satellite with the manually controlled rotors.

The receiver was originally tuned by the variable frequency oscillator (VFO) and then was later controlled by a 41.738-MHz crystal. Once crystal control was attained, no further tuning was necessary.

A filter bypass circuit was used so that the 300-Hz start tone would not be filtered out. However, this was found to be unnecessary since the eighth harmonic of the start tone was able to pass through the filter.

To prevent the facsimile recorder from starting prematurely on random noise, it was set for semiautomatic operation. When a reasonably clear signal was received, the machine was set for automatic operation. Since the machine will not start until it receives a start tone from the satellite, a few minutes of signal were lost. However, since this signal was being recorded on the tape recorder, the facsimile recorder was manually phased to reprint these pictures.

One problem encountered with the facsimile recorder was the fact that the machine had been set to receive a complete, rectangular picture in 5 minutes and 15 seconds. Since the satellite sends one square picture in 3 minutes and 20 seconds, the machine printed one and a half pictures on each frame of film. This resulted in the loss of half of every other picture, since the machine could not phase itself for the next frame of film until it received a new start tone. This problem was overcome by using a timer to measure 3 minutes and 10 seconds after the start tone was received. At this time, the recorder stopped and advanced to the next frame of film in time to be synchronized with the next tone. This procedure did not, however, have to be followed during a tape recorder playback since the tape recorder could be stopped after each picture transmission.

Satellite Tracking

In order for an APT ground station to receive data from a satellite, it must be able to determine the satellite's position in relation to its range. This is accomplished by use of an APT plotting sheet and grid, (Figures 21 and 22) furnished by the Weather Bureau, and the APT predict message.

The APT predict message shows the longitude and time that the satellite crosses the equator on several of its orbits (see Appendix C for detailed predict message information). These data will enable the station, once it has prepared its plotting sheet and grid (Appendix C), to determine the satellite position at all times.

When the station obtains its plotting sheet, a circular plastic overlay must be placed on the sheet and secured at the map's North Pole. On this sheet, the trajectory of the satellite's orbit must be plotted. This is accomplished by marking on the sheet the 2-minute subpoints given in the predict message. When these subpoints have been plotted, connecting them forms the curved trajectory of the satellite.

The next step is to locate the exact location of the ground station on the plotting sheet. The plotting grid should then be examined. The outer markings on this grid are in degrees of azimuth, while the concentric near-ellipses are 2-degree increments of great circle arc length. After examination, the grid should be placed on the plotting sheet with its center on the point marking the location of the station. The 0- to 180-degree azimuth line of this grid should be located on the station's line of longitude with the 0-degree azimuth end of the line toward the map's North Pole.

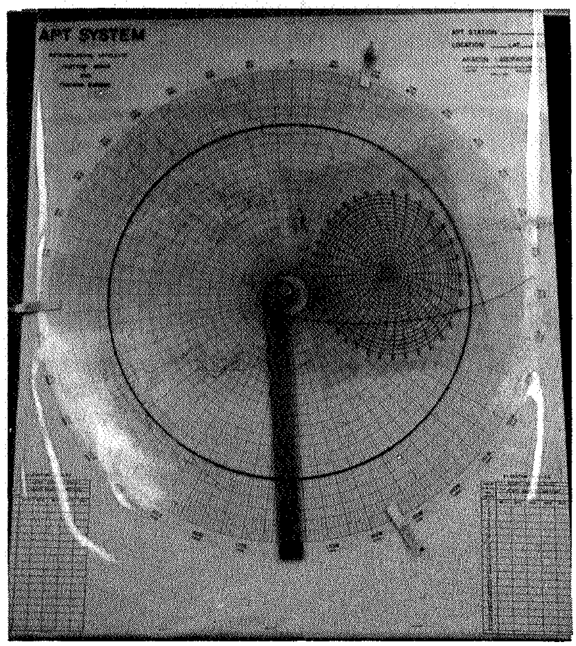

Figure 21. Plotting Board

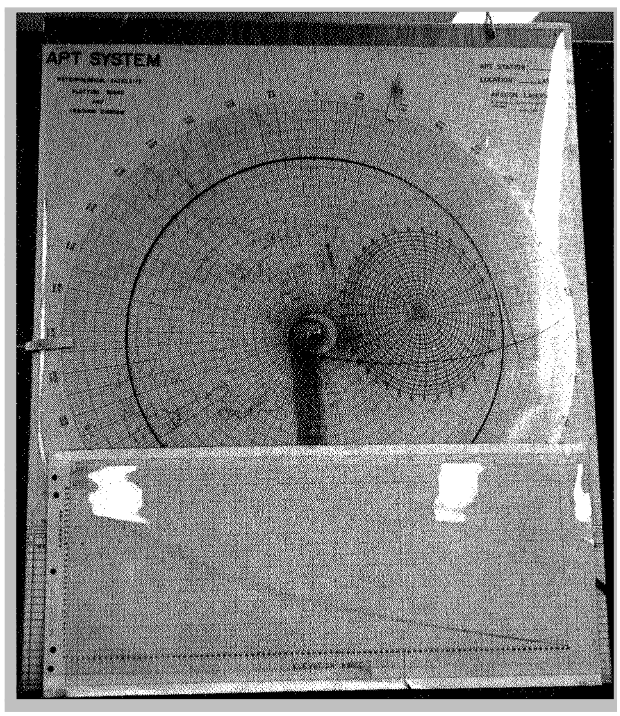

Figure 22. Plotting Board and Elevation Graph

When the grid has been correctly placed on the plotting sheet, the range of the station must be computed and marked on the grid. This is accomplished by first obtaining the present altitude of the spacecraft and then referring to Table **C-2.** The arc length figure corresponding to the present altitude of the spacecraft is the range of the station in great circle arc length. When the range has been determined, it should be marked on the corresponding near-ellipse on the grid.

The plotting sheet now should be ready for the computation of the satellite's position during an orbit. This is accomplished by first rotating the plastic overlay so that the satellite trajectory crosses the map's equator at the position corresponding to the equator crossing of the orbit that is being plotted. The subpoints on the trajectory that lie within the range of the station should then be noted. The position of these subpoints in degrees of azimuth and great circle arc length on the grid should then be noted on a worksheet similar to the one seen in Appendix C. The great circle arc length readings should be converted into degrees of elevation by use of Figure **C-5** and the present altitude of the satellite.

Once the foregoing information has been entered on a worksheet, the time at which the satellite is at each of the subpoints should be computed. This is accomplished by taking the time of the equator crossing and adding **2** minutes to it for each subpoint passed along the trajectory until the desired subpoint is reached. When this has been accomplished, the worksheet will be complete, and the antenna settings will be available for tracking the satellite.

Time Code

Each picture has a data code appearing along its left edge sent by the spacecraft master clock. This data code is in binary form with a total of five separate words. Each word is divided into 10 bits of information as shown in Table 1.

Each bit in the binary code is divided into four parts or spaces. These spaces are either black or white corresponding to the binary numerals 1 and 0. These bits form the various words which include the information given in Table 1. (See also Figure **23.)**

When a station operator learns to read the picture time code, he can forego the APT predict message by computing the time between the exit and entry of the satellite into the station's range. These data are then added to the time shown on the last picture received by the station. The result will be the time of the next satellite entry into the station's range.

Further information on the data code can be obtained from the Weather Bureau, U. S. Department of Commerce. Environmental Science Services Administration. and the Aracon *Geo*physics Division. Virginia Road, Concord. Mass.

Table 1

Data Code Formats

Word	Characteristics	Bits
1	Reference orbit number Ascending node longitude	2-5 7-10
2	Ascending node increment Ascending node time	2-4 5-10
3	Nodal period Latitude of perigee	2-5 7-10
4	Time of perigee Motion of perigee	2-7 8-10
5	Calendar day Time picture was taken	2-4 5-10

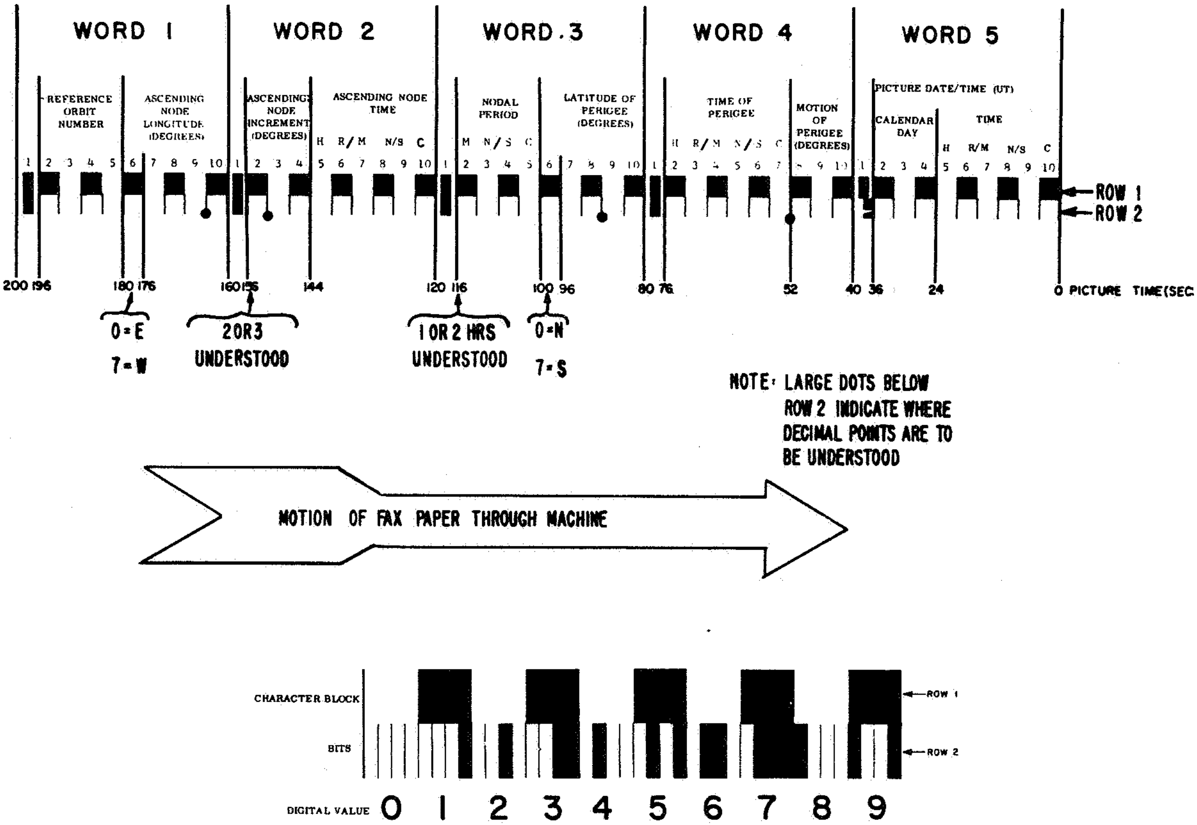

Figure 23. Operational Data Code Template

ACKNOWLEDGMENTS

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Mr. Burgess Hildreth	-	Program Director at GSFC
Mr. John C. New	-	Head of the Test and Evaluation Division
Mr. Dwight Kennard	-	Program Preceptor at the Test and Evaluation Division
Mr. Philip Yaffee	-	Head of the Electronics Test Branch of the Test and Evaluation Division
Mr. James Bailey	-	Head of the Electronic Systems Section

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APPENDIX A

GLOSSARY OF TERMS

Ascending node	A node is the point of intersection of the orbit of a planet, planetoid, or comet with the ecliptic, or of the orbit of a satellite with the plane of its primary. The ascending node is the point at which the body crosses to the north side of the reference plane; the other is the descending node.

Binary	-	A system of notation which uses only two digits, 1 and 0; therefore is used extensively in computers where the "on" and "off" positions of a switch or storage device can represent the two digits.
Bit	-	From binary digit; a unit of information.
Comparator	-	An electronic circuit that compares two signals and supplies an indication of agreement or disagreement.
Facsimile recorder	-	That portion of a facsimile receiver that converts electrical picture signals to an image of the subject copy onto the record medium.
Phase-lock oscillator	-	Oscillator in which the output signal phase is made to follow exactly the phase of a reference signal by comparing the phases between the two signals and using the resultant difference signal to adjust the frequency of the reference oscillator.
Flip-flop	-	A device having two stable states and two input terminals (or types of input signals) each of which corresponds with one of the two states. The circuit remains in either state until caused to change to the other state by application of the corresponding signal.
Perigee	-	That orbital point nearest the earth when the earth is the center of attraction. That orbital point farthest from the earth is called apogee. Perigee and apogee are used by some writers in referring to orbits of satellites, especially artificial satellites, around any planet or satellite, thus avoiding coinage of new terms for each planet and moon.
Pitch	-	Angular displacement of a vehicle about an axis parallel to the lateral axis of the vehicle.
Radiometer	-	An instrument for detecting and, usually, measuring radiant energy.

Real time	-	Time in which reporting on events or recording of events is simultaneous with the events. For example, the real time of a satellite is that time in which it simultaneously reports its environment as it encounters it; the real time of a computer is that time during which it is accepting data.
Resolution	-	The ability of a film, a lens, a combination of both, or a vidicon system to render barely distinguishable a standard pattern of black and white lines.
Retrograde	-	Motion in an orbit opposite to the usual orbital direction of celestial bodies within a given system. Specifically, of a satellite, motion in a direction opposite to the direction of rotation of the primary.
Roll	-	The act of rolling; rotational or oscillatory movement of an aircraft or similar body about a longitudinal axis through the body—called roll for any degree of such rotation.
Signal-to-noise ratio	-	A ratio which measures the comprehensibility of a data source or transmission link, usually expressed as the root-mean-square signal amplitude divided by the root-mean-square noise amplitude. The higher the S/N ratio, the less the interference with reception.
Stable platform	-	A gyroscopic device so designed as to maintain a plane of reference in space regardless of the movement of the vehicle carrying the stable platform.
Yagi antenna	-	A type of directional antenna used on some types of radar and radio equipment consisting of an array of elemental, single-wire dipole antennas and reflectors.

APPENDIX B
STATION WSM-TV GROUND STATION PLANS

The illustrations contained in this appendix are the block diagrams and schematic diagrams of the WSM-TV Ground Station equipment.

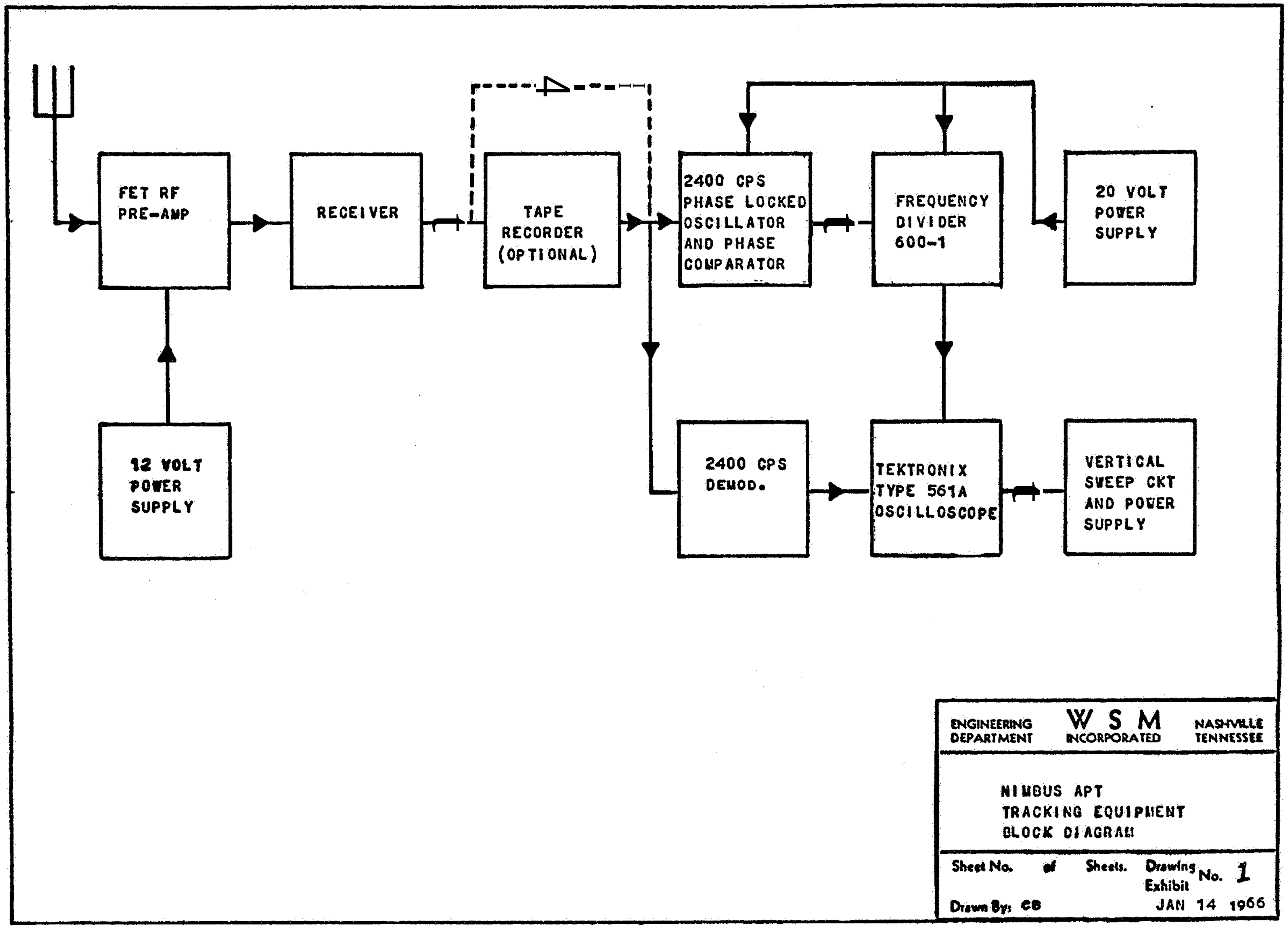


Figure B-1. Nimbus APT Tracking Equipment Block Diagram

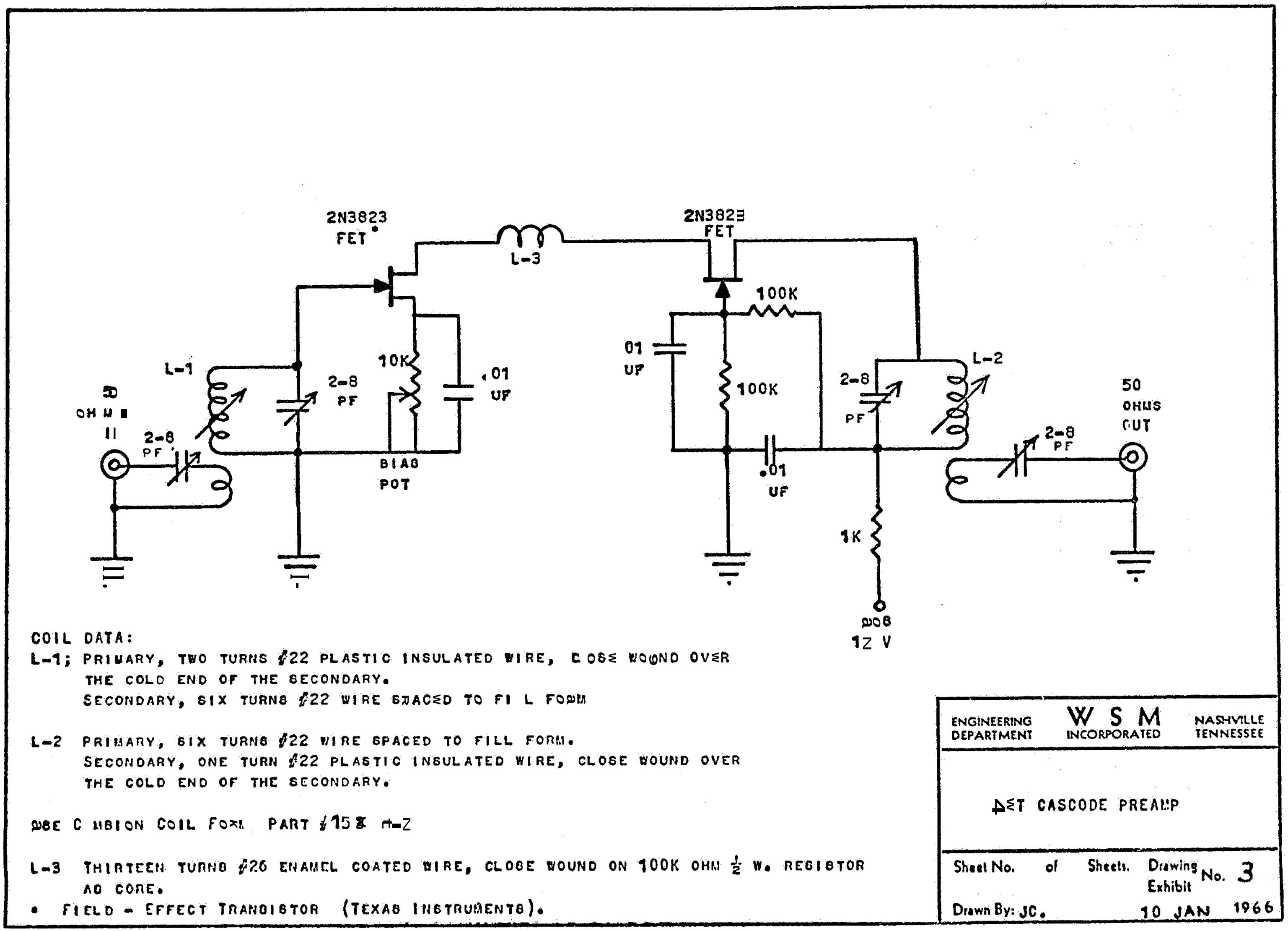
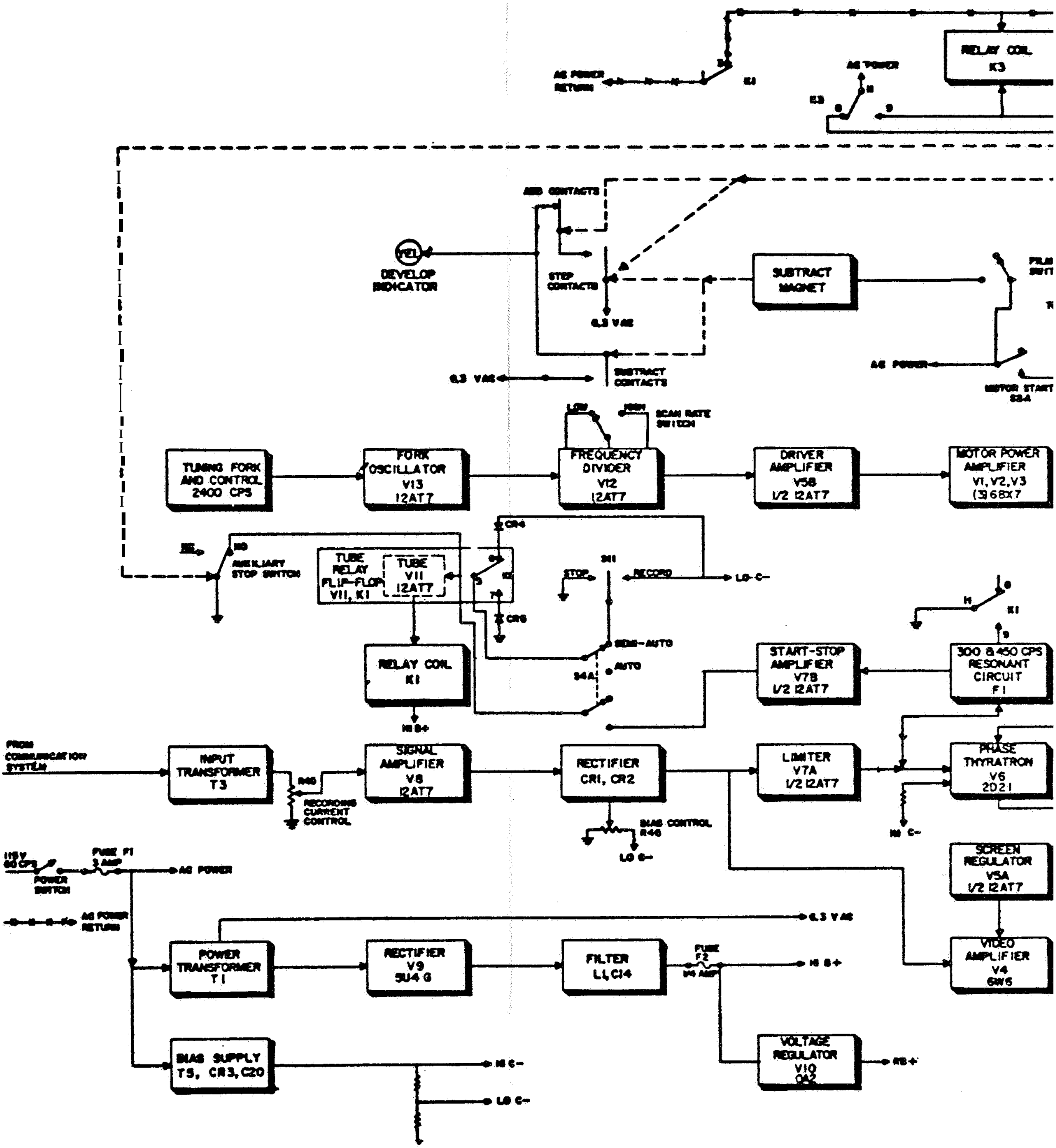


Figure B-2. FET Cascade Preamplifier Schematic Diagram



RELAY COIL K3
AC POWER RETURN
AC POWER
DEVELOP INDICATOR
SUBTRACT MAGNET
STEP CONTACTS
6.3 VAC
SUBTRACT CONTACTS
AC POWER
MOTOR START
SCAN RATE SWITCH
TUNING FORK AND CONTROL 2400 CPS
FORK OSCILLATOR V13 12AT7
FREQUENCY DIVIDER V12 12AT7
DRIVER AMPLIFIER V5B 1/2 12AT7
MOTOR POWER AMPLIFIER V1, V2, V3 (3) 6BX7
AUXILIARY STOP SWITCH
TUBE RELAY FLIP-FLOP V11, K1
TUBE V11 12AT7
STOP
RECORD
LO C-
SEMI-AUTO
AUTO
RELAY COIL K1
START-STOP AMPLIFIER V7B 1/2 12AT7
300 & 450 CPS RESONANT CIRCUIT F1
HI B+
FROM COMMUNICATION SYSTEM
INPUT TRANSFORMER T3
RECORDING CURRENT CONTROL
SIGNAL AMPLIFIER V8 12AT7
RECTIFIER CR1, CR2
BIAS CONTROL
LO C-
LIMITER V7A 1/2 12AT7
PHASE THYRATRON V6 2D21
HI C-
SCREEN REGULATOR V5A 1/2 12AT7
115V 60 CPS
POWER SWITCH
FUSE F1 3 AMP
AC POWER
AC POWER RETURN
6.3 VAC
POWER TRANSFORMER T1
RECTIFIER V9 5U4 G
FILTER L1, C14
HI B+
VIDEO AMPLIFIER V4 6W6
VOLTAGE REGULATOR V10 OA2
BIAS SUPPLY T5, CR3, C20
HI C-
LO C-

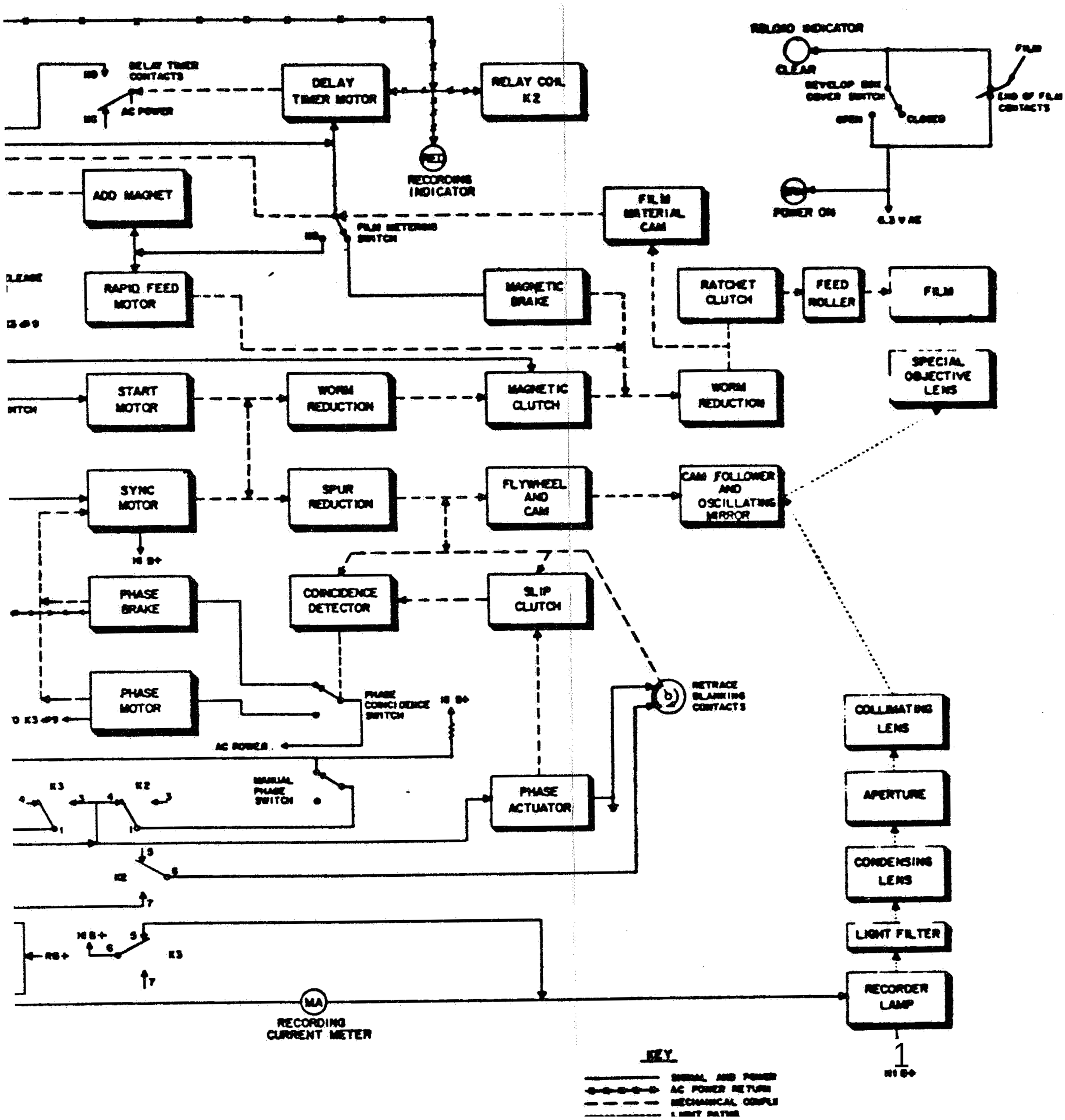


Figure B–3. Facsimile Recorder Block Diagram

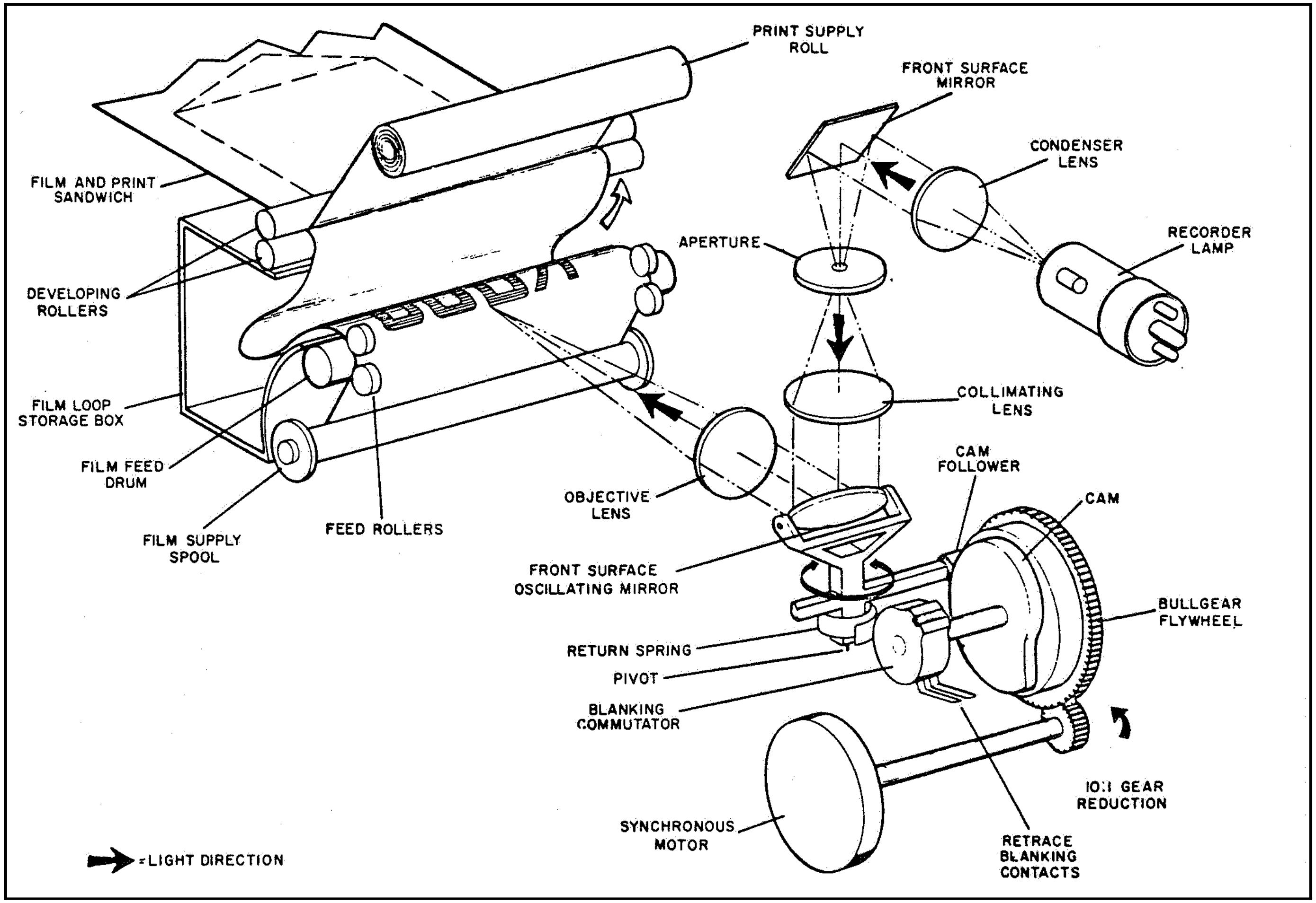


Figure B-4. Receiver Optical Scanning System

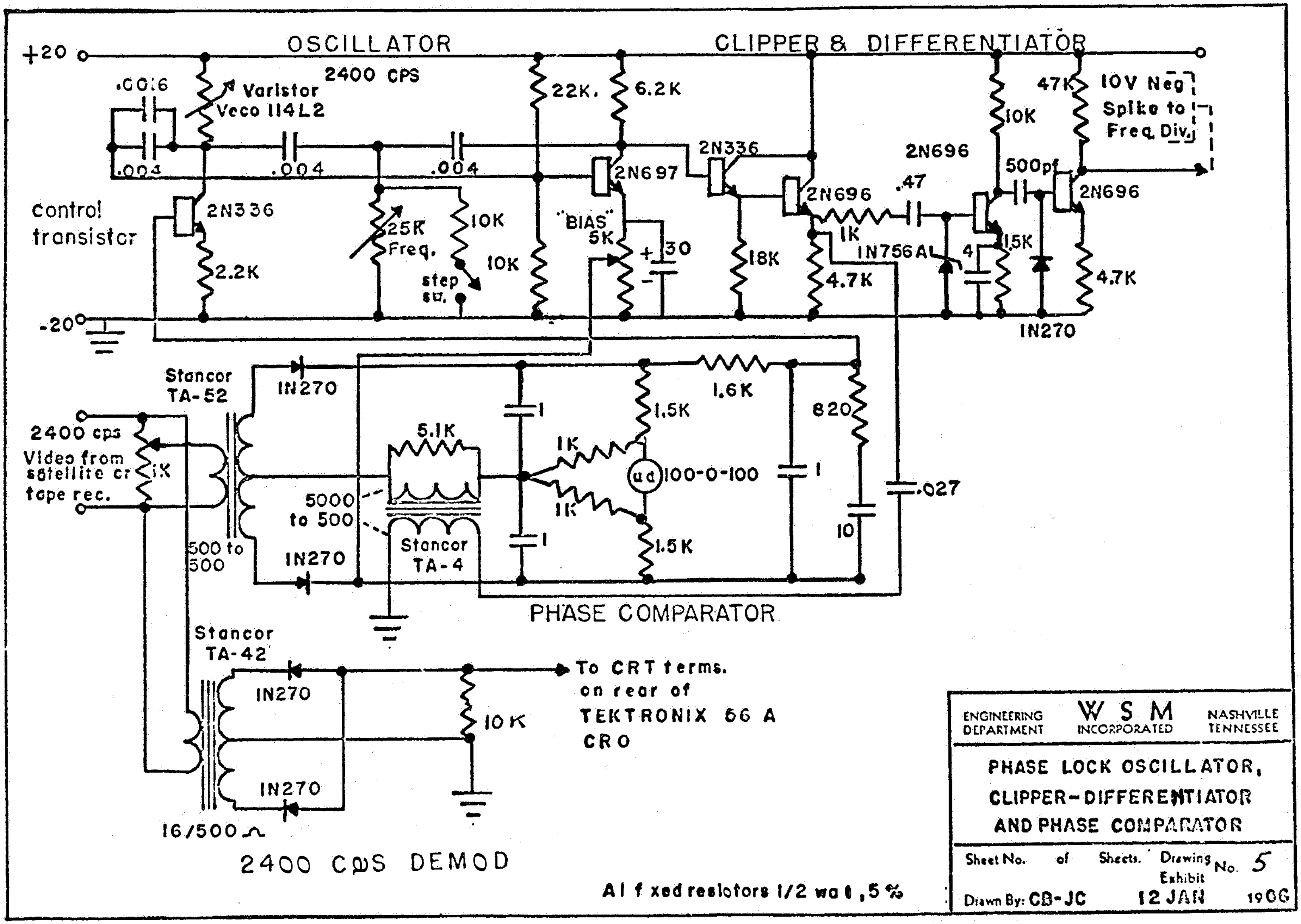


Figure B-5. Phase-Lock Oscillator, Clipper-Differentiator, and Phase Comparator, Schematic Diagram

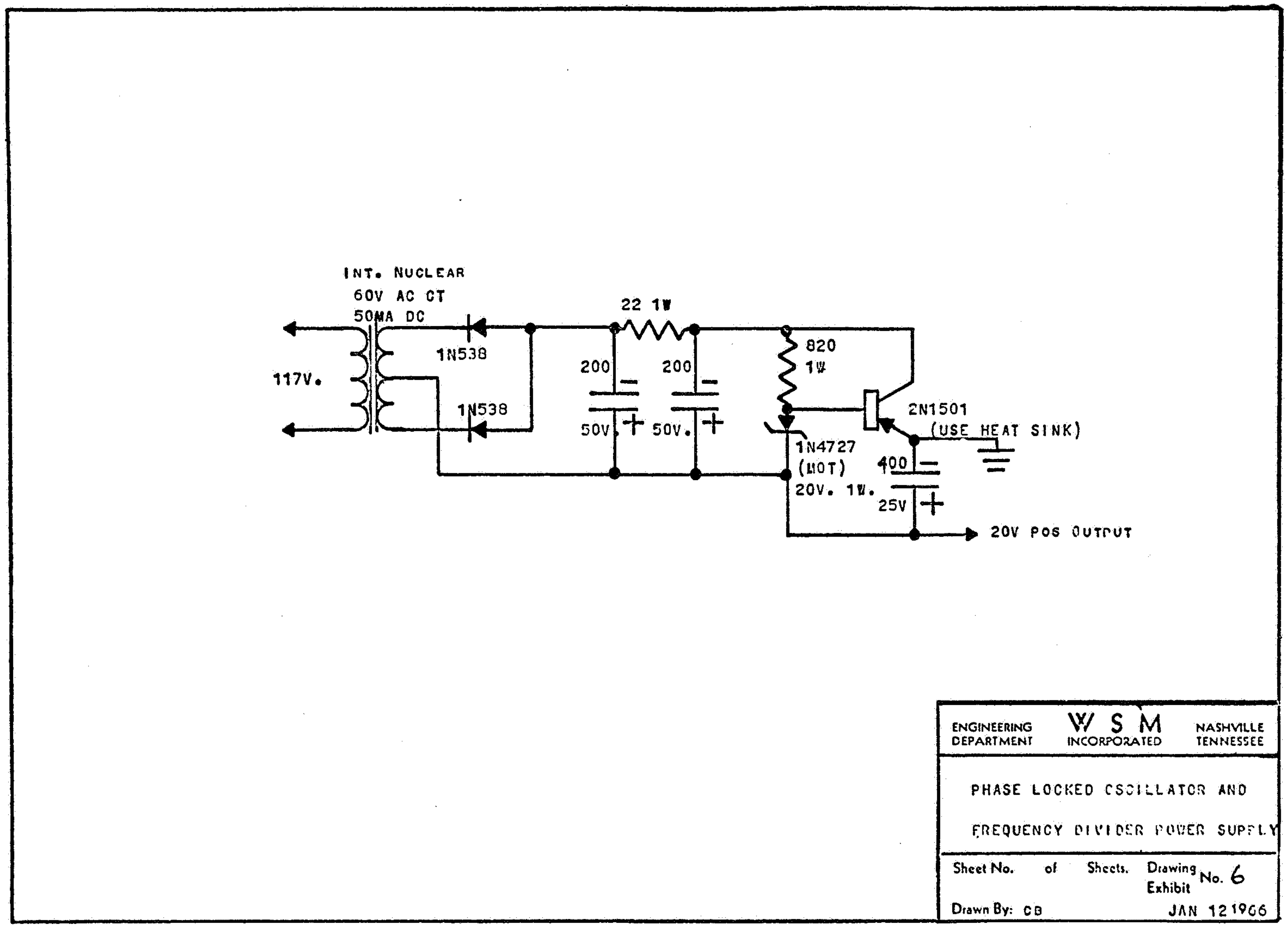


Figure B-6. Phase-Locked Oscillator and Frequency Divider Power Supply Schematic Diagram

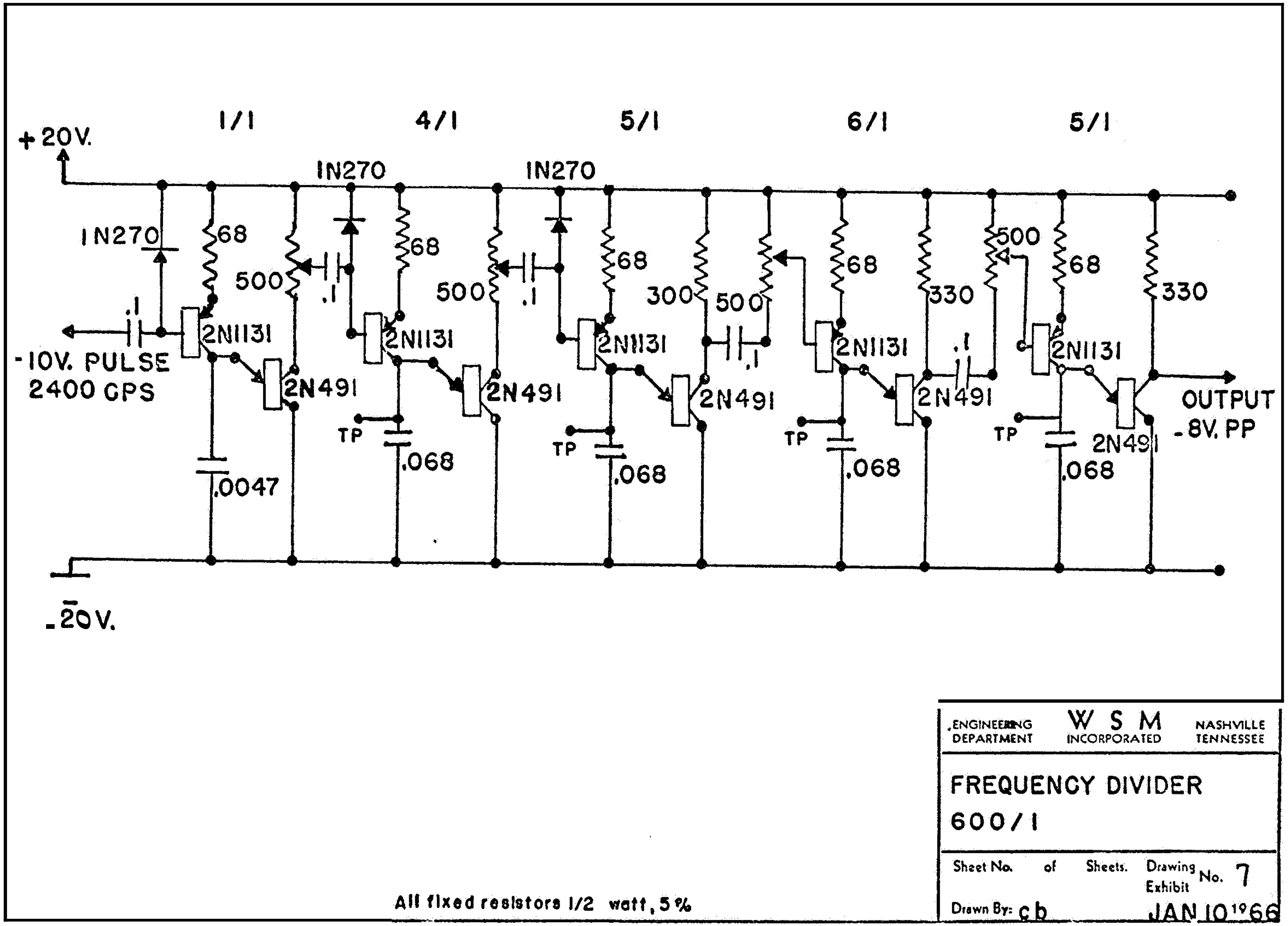


Figure B-7. Frequency Divider Schematic Diagram

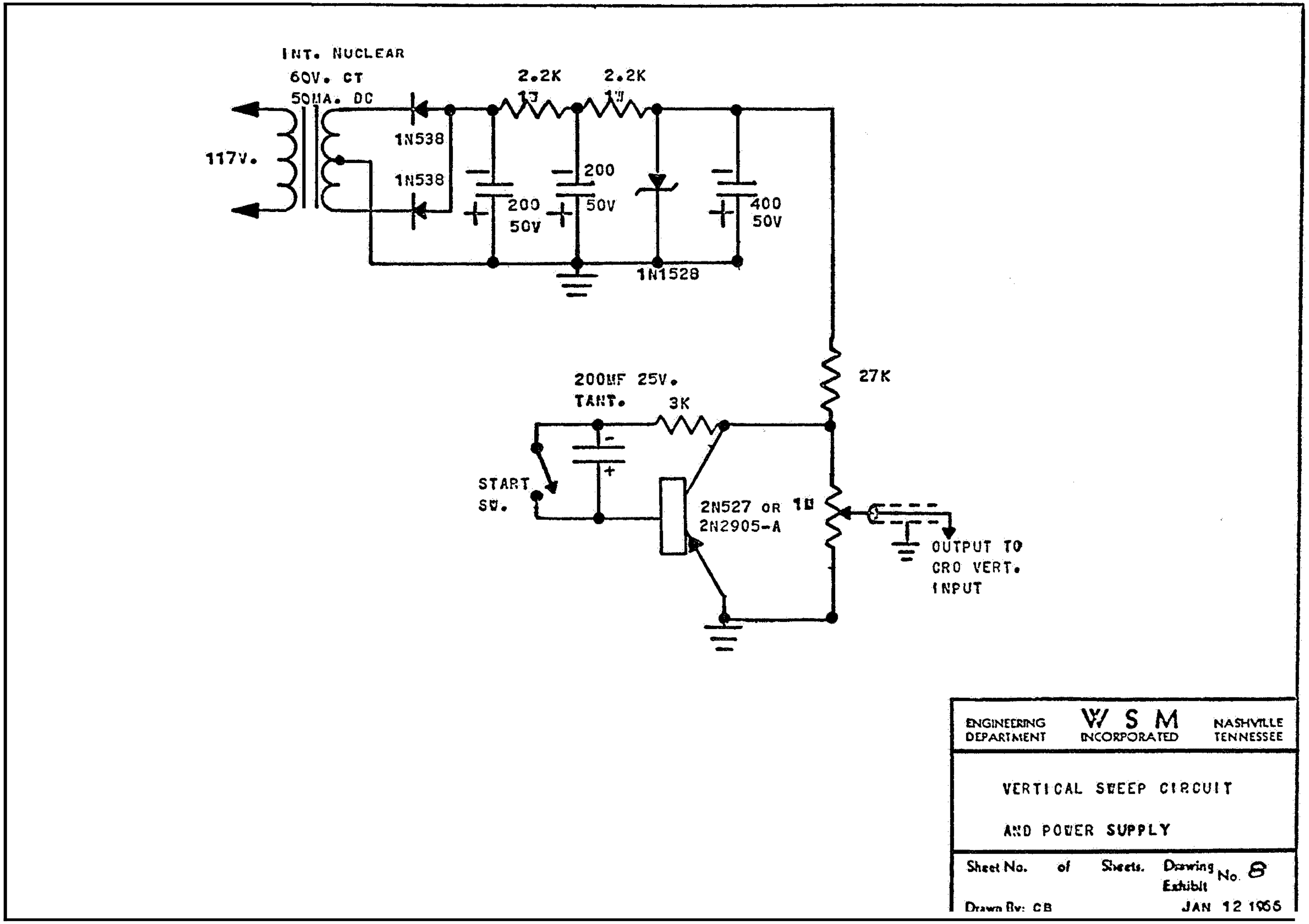


Figure B-8. Vertical Sweep Circuit and Power Supply Schematic Diagram

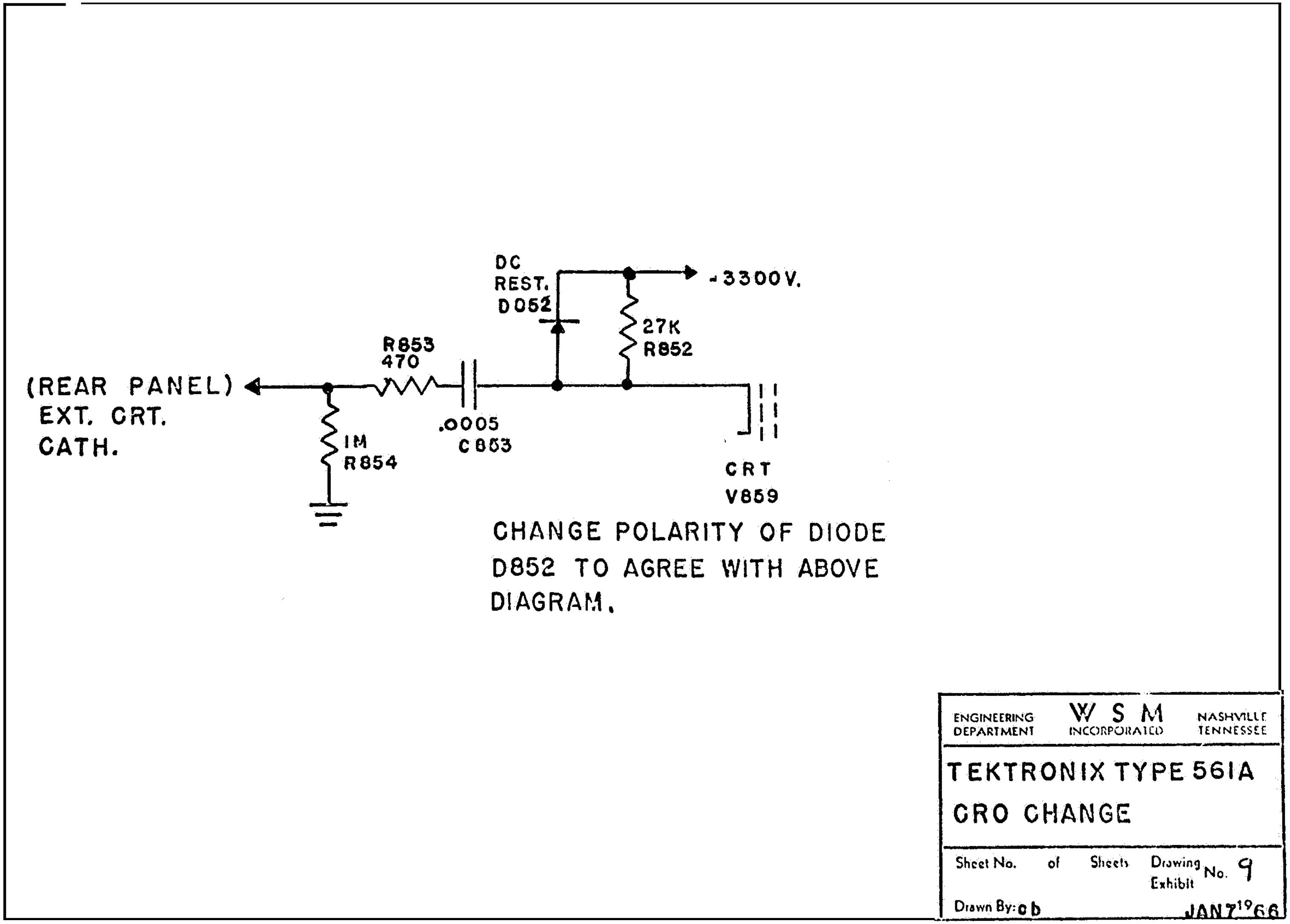


Figure B-9. Tektronix Type 561A CRO Change, Schematic Diagram

APPENDIX C

SATELLITE TRACKING DATA

This appendix contains the prediction data, conversion data, and tracking worksheet required to track the satellite.

Table C-1

Explanation of Code Symbols

Code	Explanation
TBUS 2	APT Bulletin originating in the United States south-to-north picture-taking orbit
KWBC	Traffic entered at Washington, D. C.
APT PREDICT	Identifies message content
MMYYSS	Message serial number MM - month of year YY - day of month SS - number of spacecraft to which predict applies
PART I	Equator crossing predicts follow.
$ON_rN_rN_rN_r$ $OY_rY_rG_rG_r$ $Og_rg_rs_rs_r$	
O	Indicator, reference orbit equator crossing information follows (Note: Information in Parts II and III applies directly to this reference orbit.)
$N_rN_rN_rN_r$	Number of reference orbit
$Y_rY_rG_rG_rg_rg_rs_rs_r$	Day (YY), hour (GG), minute (gg), and second (ss)-GMT- on which satellite crosses the equator northbound on the reference orbit $N_rN_rN_rN_r$
$Q_rL_oL_ol_ol_o$	Octant and longitude in degrees and hundredths at which satellite crosses the equator northbound on reference orbit $N_rN_rN_rN_r$; (octant at equator will be that into which the satellite is moving.)
T	Indicator, nodal period follows
ggss	Nodal period, minutes and seconds between consecutive equator crossings; (hundreds group will not be included: ex. 100 minutes 13 seconds will be coded as 0013)

Table C-1 (Continued)

Explanation of Code Symbols

Code	Explanation
L	Indicator, nodal longitude increment follows
$L_oL_o1_o1_o$	Degrees and hundredths of longtitude degrees between consecutive equator crossings
$N_4N_4N_4N_4$	Number of the fourth orbit following the reference orbit
$G_4G_4g_4g_4s_4s_4$	Hour (GG), minute (gg), and second *(ss)*, at which satellite crosses the equator northbound on orbit $N_4N_4N_4N_4$
$Q_4L_oL_o1_o1_o$	Octant and longitude in degrees and hundredths at which satellite crosses equator northbound on orbit $N_4N_4N_4N_4$
$N_8N_8N_8N_8$	8th and 12th orbits following reference orbit
$N_{12}N_{12}N_{12}N_{12}$	
PART II	Satellite altitude and subpoint coordinates at 2-minute intervals — after time of equator crossing follows
$02Z_{02}Z_{02}Q_{02}$	
02	Information pertinent to 2 minutes after equator crossing follows
$Z_{02}Z_{02}$	Satellite altitude in tens of kilometers; at 2 minutes after equator crossing
Q_{02}	Octant of globe at 2 minutes after equator crossing
$L_aL_aL_aL_oL_oL_o$	
$L_aL_aL_a$	Latitude of satellite subpoint in degrees and tenths of degrees at 2 minutes after equator crossing

Table C-1 (Continued)

Explanation of Code Symbols

Code	Explanation
$L_oL_oL_o$	Longitude of satellite subpoint in degrees and tenths of degrees at minute 2 after equator crossing
(This information is repeated at 2-minute intervals over the sunlit portion of the orbit north of the equator.)	
PART III	Satellite altitude and subpoint coordinates at 2-minute intervals prior to time of equator crossing follows
$02Z_{02}Z_{02}Q_{02}$	
02	Information pertinent to minute 2 before equator crossing follows
$Z_{02}Z_{02}$	Satellite altitude in tens of kilometers at 2 minutes before equator crossing
Q_{02}	Octant of globe at 2 minutes before equator crossing
$L_aL_aL_aL_oL_oL_o$	
$L_aL_aL_a$	Latitude of satellite subpoint in degrees and tenths of degrees at minute 2 before equator crossing
$L_oL_oL_o$	Longitude of satellite subpoint in degrees and tenths of degrees at minute 2 before equator crossing
PART IV	Remarks

```
GNI005A
PP GNIM GOSI GULA LTAN GHNJ GAVE GLGE GYRS GALA AADE HMSC LCYI GAGO
GTOS
DE GTOS 003
01/1737Z
HMSC ATT ET34
GALA/R-AERO-YA R-COMP-RRF
AADE/PASS TO GIBBS VEATHER MELBOURNE
GAVE/B TAYLOR

TBUS1
APT PREDICT
070402
PART I
01598 00412 05010 21309 T1331 L2838
16022 02416 00043
16060 35822 11396
PART 11
16402 497959 18402 557921 20413 615372
22413 672802 24413 724694 26423 767514
25423 790225 30420 779094 32420 743315
34420 693445 36420 638527 313420 580583
40420 521625 42420 461658 44420 400685
46410 339709 48410 277730 50410 215750
52410 153768 54400 091786 56400 029303
PART III
58405 033820 60405 095837 62405 157555
64405 220873 66395 282893 68396 344914
70396 405939
PART IV     TRANSMISSION FREQUENCY  137-50  MC

TBUS2
APT PREDICT
070400
PART I
00659 00413 01657 02633 T0810 L2704
06732 02938 13450
06770 34219 21734
06811 05460 30917
PART II
02180 065280 04180 131297
06130 I96315 08180 261334
10180 335355 12190 390377
14190 454404 16190 517436
18190 550477 20190 641532
22190 699615 24180 752755
26181 789006 28181 795367
30171 754655
PART III
02175 065246 04175 131229
06175 196211 08175 261192
10165 326172 12165 391149
14165 455122 16165 519090

01/1741Z JUL GTOS
```

Figure C-1. APT Predict Message

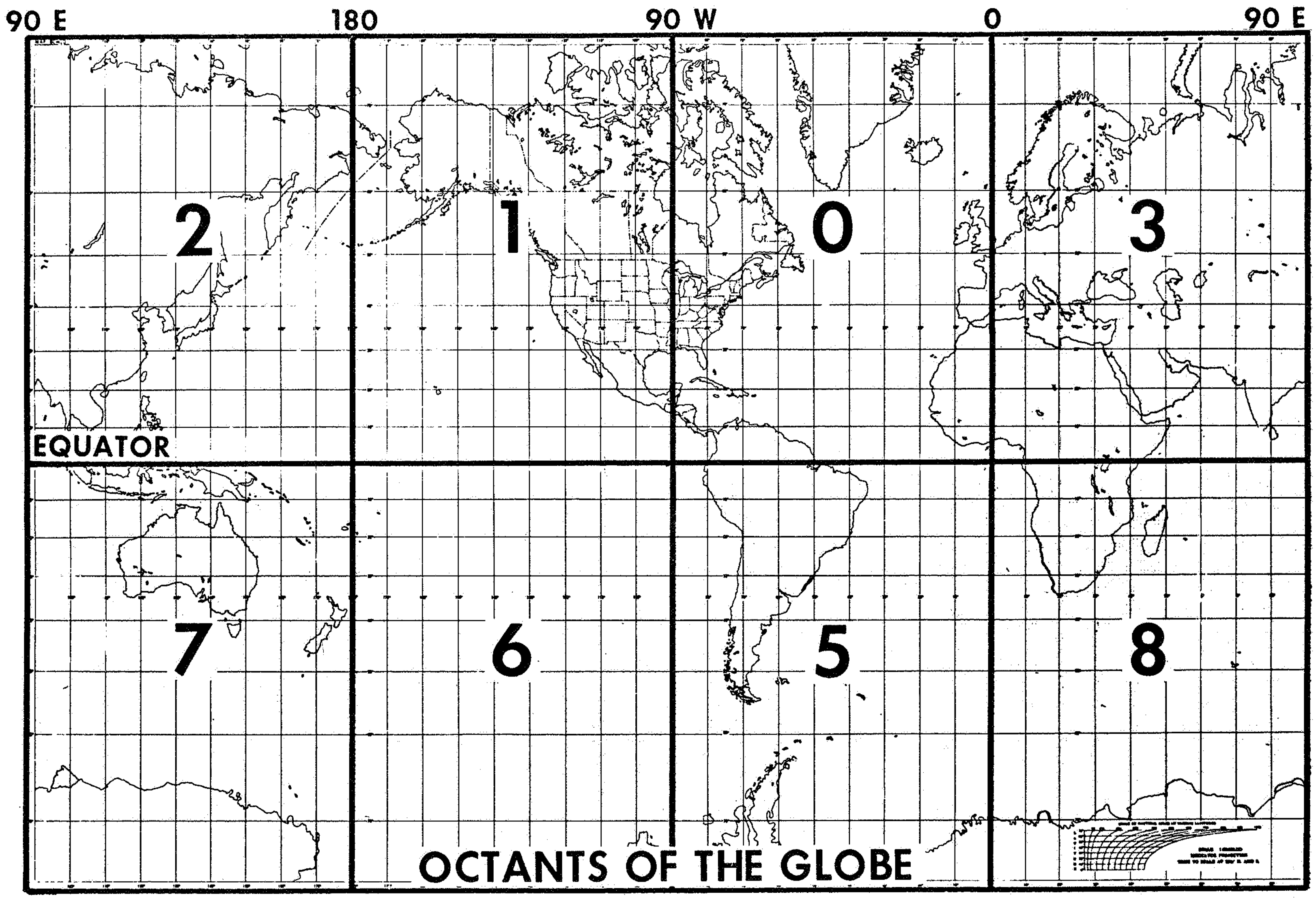


Figure C-2. Octants of the Globe

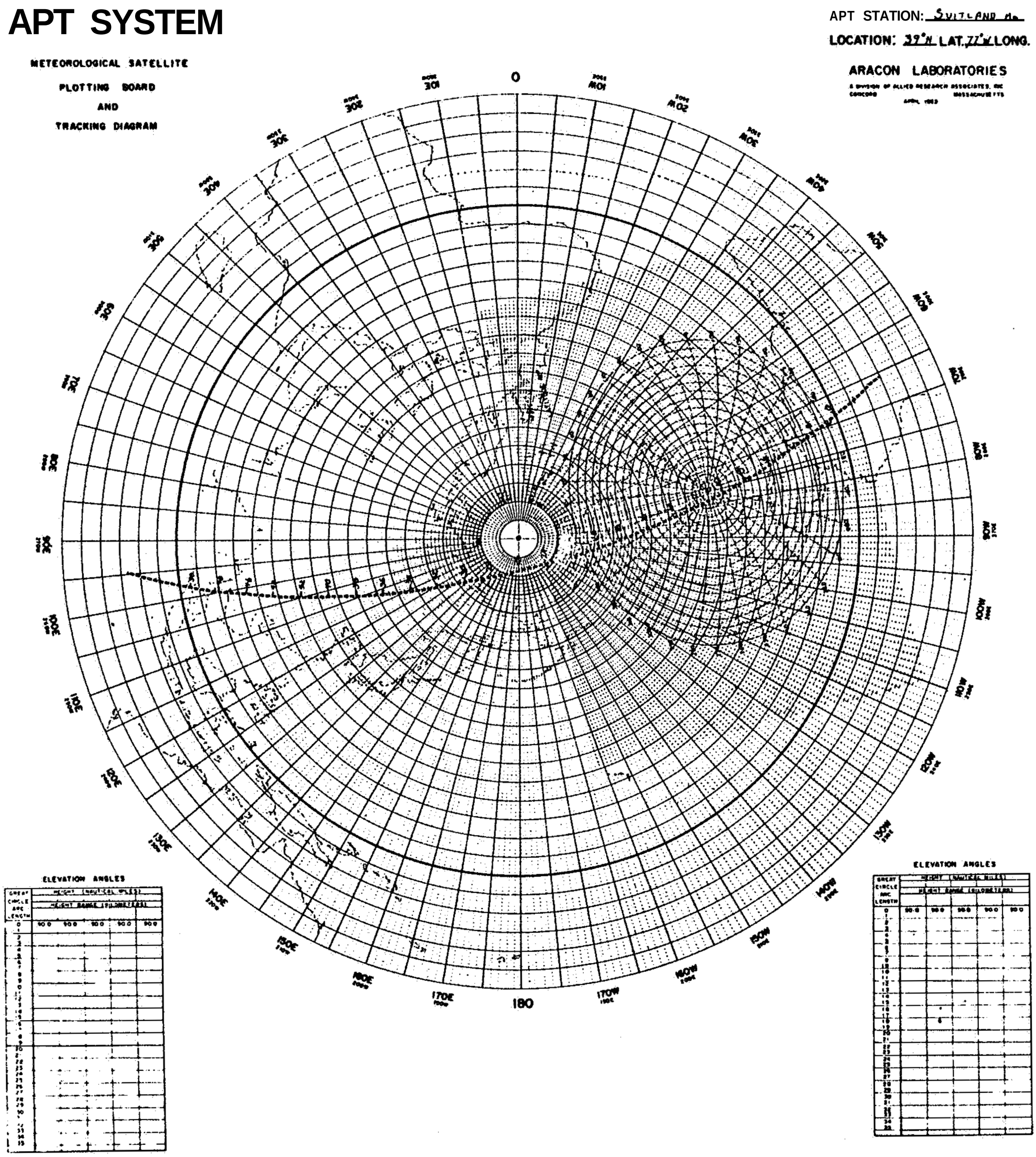


Figure C-3. Plotting Board and Tracking Diagram

WB FORM 813-39
3 - 64

U.S. DEPARTMENT OF COMMERCE
Weather Bureau

APT TRACKING WORKSHEET

STATION: Suitland, Md.

ORBIT NO.: 0020 (Nimbus A)

DATE: 29 August 1964

SIGNAL ACQUISITION

TIME	ELEVATION	AZIMUTH

TIME ASC. NODE REF.	(Z)	AZIMUTH	ELEVATION	GREAT CIRCLE DISTANCE	PICTURE TIME	REMARKS
3	16:11:46	172	0	28.2		Equator Crossing
4		173	3.7	25.0		16:08:46Z
5	16:13:46	174	8.0	21.5		68.4°W
6		176	13.2	18.0		
7	16:15:46	179	18.0	14.5		
a		180	27.1	11.0		
9	16:17:46	185	41.2	7.1		
10		190	57.3	4.0		
11	16:19:46	250	80.5	1.0		Max. Elevation
12		320	60.0	3.5		
13	16:21:46	338	40.2	7.0		
14		342	26.5	10.3		
15	16:23:46	344	17.1	14.0		
16		345	10.1	18.0		
17	16:25:46	345	2.0	23.6		
18		346	0.6	25.0		
19	16:27:46	347	0	29.0		

WB Form 813-39 (3-64) USCOMM-WB-DC

Figure C-4. APT Tracking Worksheet

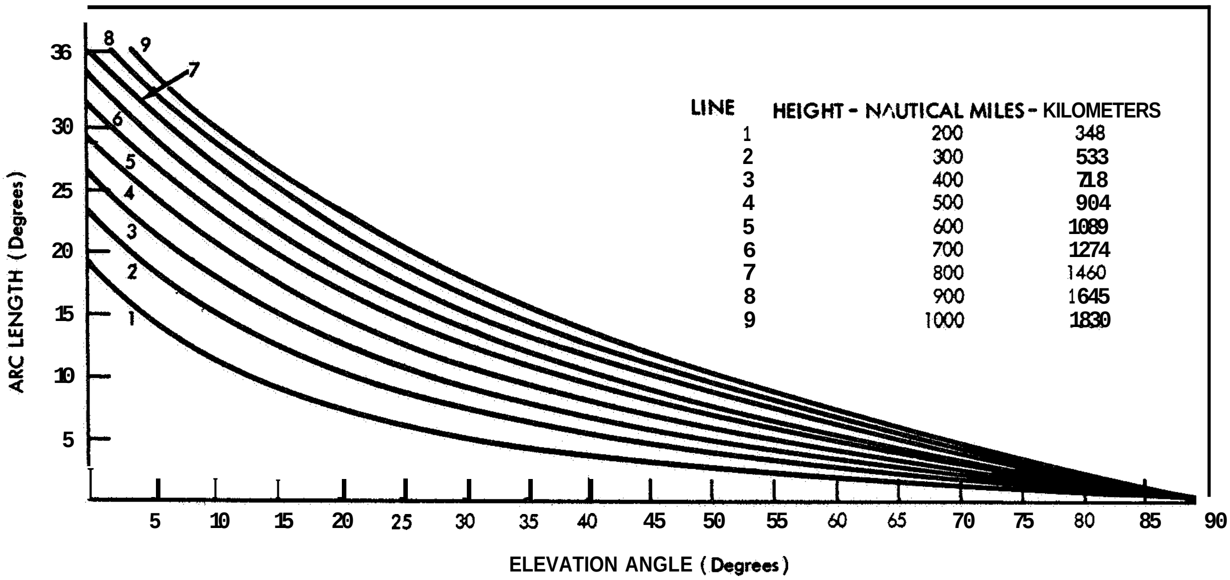


Figure C-5. Conversion Chart-Great Circle Arc Length Readings vs. Elevation Angle

Table C-2

Conversion from Zero-Degree Elevation
to Great Circle Arc Length

Height (nautical miles)	Arc Length	Height (kilometers)	Arc Length
100	13.6	200	14.2
125	15.2	250'	15.8
150	16.6	300	17.3
175	17.9	350	18.6
200	19.1	400	19.8
225	20.2	450	20.9
250	21.2	500	22.0
275	22.2	550	23.0
300	23.1	600	23.9
325	24.0	650	24.9
350	24.8	700	25.7
375	25.6	750	26.5
400	26.4	800	27.3
425	27.1	850	28.1
450	27.8	900	28.8
475	28.5	950	29.5
500	29.2	1000	30.2
525	29.8	1050	30.9
550	30.4	1100	31.5
575	31.0	1150	32.1
600	31.6	1200	32.7
625	32.2	1250	33.3
650	32.7	1300	33.9
675	33.3	1350	34.4
700	33.8	1400	34.9
725	34.3	1450	35.5
750	34.8	1500	36.0
775	35.3	1550	36.5
800	35.8	1600	36.9
825	36.2	1650	37.4
850	36.7	1700	37.9
875	37.1	1750	38.3
900	37.6	1800	38.8